



# How to consider history in landscape ecology: patterns, processes, and pathways

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## Abstract

**Context** Landscape ecology early on developed the awareness that central objects of investigation are not stable over time and therefore the historical dimension must be included, or at least considered.

**Objectives** This paper considers the importance of history in landscape ecology in terms of its impact on patterns and processes and proposes to complement these with the notion of pathways in order to provide a comprehensive analysis of landscape change.

**Methods** We develop a conceptual framework distinguishing between legacy effects, which include

pattern and processes, and path dependence, with a focus of development pathways and we illustrate these perspectives by empirical examples.

**Results** Combined short- to long-lasting imprints and legacies of historical patterns and processes reveal how present patterns and processes are in various ways influenced by legacies of the past. The focus on inherent dynamics of development pathways sheds light on the process of change itself, and its trajectories, and reveals the role of event chains and institutional reproduction.

**Conclusions** Understanding patterns, processes, and pathways over time, allows a more complete analysis of landscape change, and forms the base to preserve vital ecosystem services of both human-made and natural landscapes for the future.

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## Introduction

The development of landscape ecology was accompanied by the awareness that the central objects of investigation, such as patterns and processes (Turner 1989, Turner et al. 2003), are not stable over time and therefore the historical dimension must be included, or at least considered (e.g. Rhemtulla and Mladenoff

2007). Consideration of history contains various degrees of complexity. On the most straightforward level, it is obvious that present landscape patterns are shaped by past landscape patterns. The complexity increases if instead of only focusing on stability, we also include changes in patterns and processes. Previous conditions and past processes, such as anthropogenic activities can, for example, show an impact on current landscape patterns or processes (Monger et al. 2015). Such effects are summarized by the term ‘legacy effect’ (Bürgi et al. 2017b). However, so-called time-lags might blur the picture, as initiating activities might now show immediate effects (e.g. Li et al. 2017). Historically, cause–effect relationships can be repeated and lead to accumulated ‘time lags’ (du Toit et al. 2016 and references therein). In their study on drivers of natural grassland change in an urban setting du Toit et al. (2016) show that time lags infer potential extinction debts of contemporary urban vegetation, with important consequences for future biodiversity. Ziter et al. (2017) adds the significant point of the strong linkages between landscape patterns and ecosystem services (ES) supply, as ES assessments often rely on land-cover maps (Martínez-Harms and Balvanera 2012). Here, the fact is raised that ES supply is mostly assessed without considering land-use legacies. More precisely, it is proven that including land-use history significantly contributes to improved ES assessments for a broad range of ES, and for various landscapes (Gimmi et al. 2013; Schrama et al. 2016; Miyasaka et al. 2017; Ziter et al. 2017; Schirpke et al. 2020).

In this contribution we propose to consider the history in landscape ecology, not only regarding its effect on patterns and processes, but also to specifically look into the pathways of landscape change. Considering the later with the characteristics of the related trajectories stands at the base of moving from analyzing the past and the present, to thinking about potential future developments, as “today’s land-use decisions will generate tomorrow’s legacies [...]” (Ziter et al. 2017). Similar claims have been raised by Antrop (2005).

Here we follow a definition provided by Britt (1993), using the term trajectory for a development which is traceable to individual variables that are plotted over time, talking about pathways if the focus is on the dynamic feedback between variables of change. The analysis of longer-term landscape

dynamics has also been promoted by Rhemtulla and Mladenoff (2007), with a focus on the biophysical history of an ecosystem in a broader perspective, but also in terms of the historical interplay between human and natural drivers. Bürgi and Gimmi (2007) state that concepts for systematically considering the human dimension over time are largely missing, while Arce-Nazario (2007) claims that historical influences must not be solely targeted to human-induced events, but also to natural disturbances which are needed to thereby trace altered human decisions and effective landscape management. Cusser et al. (2018) ultimately address biodiversity directly, the basis for the functional diversity of our ecosystems, and thus the bundles of provided ES. If we succeed in understanding patterns, processes, and pathways over time, it will also be possible to preserve vital ecosystem services, of both human-made and natural landscapes, for the future.

With this statement we underline the necessity of interdisciplinary cooperation for the study of long-term landscape development. In addition to collaborating with obvious potential partners such as palaeoecologists or archaeologists (see e.g. Arikan et al., this issue), cooperation and inspiration should also be sought in exchange with less obvious disciplines. In the following we will illustrate this using the concept of path dependence, originally developed in economics (David 1985; Arthur 1989), but further adapted in political science (e.g. Pierson 2000), historical ecology (Crumley 2007; Szabó 2015), historical sociology (e.g. Goldstone 1998; Mahoney 2000; Djelic and Quack 2007), and rural studies (e.g. Libecap 2009; Clar and Pinella 2011; Wilson 2014) to name but a few.

We propose in the following a conceptual framework in which we distinguish between legacy effects, which include pattern and processes, and path dependence, with a focus of development pathways and we illustrate both perspectives by empirical examples. Path dependence recently appeared in various (inter-)disciplinary and topical context, such as climate change (Levin et al. 2009) and environmental policy (Kirk et al. 2007; Van Buuren et al. 2016; Yona et al. 2019), but to date has only rarely been applied to landscape research. We take up the line of thoughts developed in Zariņa (2013) and propose that applying the concept of path dependence for the study of landscape development complements the well-

established approach of studying the historical dimension of landscapes in a compelling and fruitful way.

We aim to outline the main strands of research considering the historical dimension in landscape ecology as expressed in patterns and processes and address the complementarity and added value of also looking into landscape pathways.

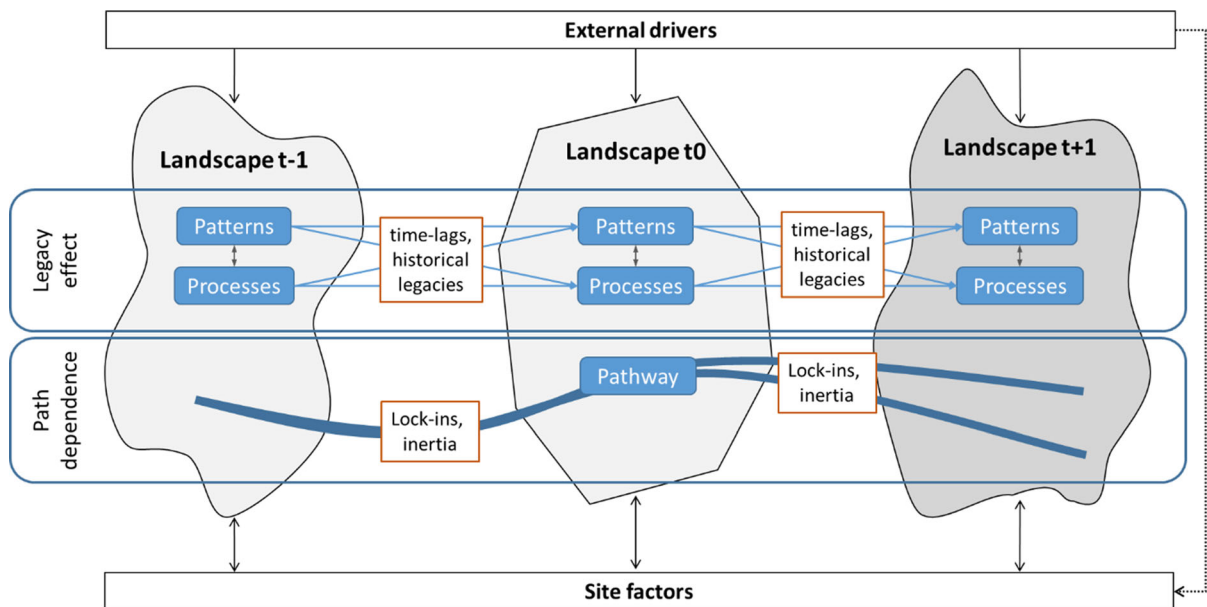
### Patterns, processes, pathways

Present patterns and processes are shaped not only by present conditions, but are, in various ways, influenced by patterns and processes of the past. Combined short- to long-lasting imprints and legacies of historical patterns and processes, therefore, also shape the likelihood of potential future developments. Understanding the role and relevance of such legacy effects, including connected time lags, on landscape development is of high interest for the field of landscape ecology.

We will follow a conceptual framework that deals with different aspects of the impact of past conditions on the current landscape (Fig. 1). We distinguish between legacy effects on patterns and processes and

their interaction over time and we stress the importance of considering time lags effects, either because the system is persistent until a certain threshold is reached (in case of continuous changes of drivers, e.g. erosion due to cumulative effects of a change in grazing pressures over time) or due to system characteristics that require time for regime-shift effects to lead to transformation (e.g. abandonment leading to reforestation). Long-term development of landscapes is additionally shaped by external drivers and local site factors, which are also interrelated (Fig. 1).

Various approaches have been developed to study and better understand the constraints of long-term trajectories of landscape development, such as the driving force analysis (Geist and Lambin 2002; Bürgi et al. 2004), causal chain analyses (Loran et al. 2018), landscape biographies (Kolen and Renes 2015), nested chains of explanations and causal eventism (Walters 2017), Landscape Change Trajectory Analyses (LCTAs) (Käyhkö and Skånes 2008) or path dependence (Zariņa 2013—see also Palang et al. 2019). We propose to put more weight on the inherent dynamics of landscape development, i.e. the pathways, by adopting the concept of path dependence in landscape ecology. We are aware, that in this field the term so far



**Fig. 1** Since its early times, landscape ecology considered the historical dimension of its two core concepts, i.e. patterns and processes, which over time have an impact on each other, and combined stand for legacy effects. We propose to additionally

adapt the perspective of path dependence of landscape development, where aspects such as sequence of events and inertia and their effect on development pathways stand at central stage

has been foremost used in the sense of ecology pathways, i.e. migration pathways along corridors and in connectivity analyses (e.g. Dondina et al. 2018; Tracy et al. 2019). Additionally, it is also used to describe adaptation pathways (e.g. Virah-Sawmy et al. 2016) i.e. ways in which ecosystems and/or species can adapt to environmental changes, such as climate change. We propose to use the term path dependence in the sense of landscape pathways, to describe the sequential stages in the development of landscape, offering a supplementary perspective to the study of legacy effects (Fig. 1), which could also be called to represent “past dependence”.

## Understanding legacy effects

### Patterns

A landscape pattern is the result of the relationship between abiotic and biotic conditions and interactions, such as climate, landform, disturbance, succession and competition (Turner 2005). Among them succession following disturbance, or human land-use change, are key causes of time lags affecting the landscape pattern. Such legacy effects have been well described for many systems, but more often with a focus on ecosystems (e.g. Bürgi et al. 2017b), i.e. not addressing in an encompassing way the question what aspects of current landscape patterns are explained by disturbance or past land use, for how long such influences persist, and when and why the effects lead to transformation. In the following, we present some of the core contributions to the field.

Many studies have addressed the influence of land-use history in explaining the vegetation pattern of contemporary landscapes, with palaeoecologists being able to show how the natural environment has been shaped by human presence since ancient times. In north-eastern France, soil nutrient availability, species richness, and plant communities, still varied 2000 years after deforestation during Roman occupation, with the intensity of former agriculture causing a distinctive pattern at landscape level (Dupouey et al. 2002). Recently, Florenzano (2019) showed that pollen and non-pollen palynomorphs evidence from archaeological sites in southern Italy reflected 2500 years of mainly pastoral human activities after the opening of the forest, starting with Messapian

populations and Greek colonizers, and increasing significantly during the Roman occupation period (2100–1500 cal. BP), as the land use history had greatly contributed to a shift in the floristic composition towards the current plant biodiversity and a patchwork of habitats, including open areas. Hence, the present-day vegetation pattern can be considered a legacy of long-term historical distribution and land use. For grasslands in rural landscapes in Sweden, Cousins (2009) tried to disentangle long-term land use change and environmental properties at a landscape scale by reconstructing grassland decline over more than 200 years in dependence of soil patterns and analyzing the relationship of plant species to landscape change. Landscapes dominated by clay soils were converted to crop-fields quite early, whereas grasslands on coarser soils declined later, primarily to forest. Interestingly, grasslands in landscapes with more than 10% semi-natural grassland left today had 50% higher species richness of all grasslands, including both abandoned and new grassland, showing that plant species patterns in grasslands at local scales are determined by broader landscape processes which may have occurred many centuries ago.

The existence of time-lagged biodiversity responses of land-use changes is widely recognized (e.g. Metzger et al. 2009; Rhemtulla et al. 2009; Ewers et al. 2013). Quantifying land-use changes of semi-natural grasslands in southern Sweden and species inventories, Auffret et al. (2018) showed that despite local factors being the best predictors of specialist richness, the historical landscape pattern predicts present-day richness better than the contemporary landscape, indicating that further species losses could occur in the future. Such extinction debts pose a significant, but often unrecognized, challenge for biodiversity conservation across a wide range of taxa and ecosystems (Kuussaari et al. 2009; Jackson and Sax 2010). Similarly, Tello et al. (2020) argue that historical land-use legacy of former agroforestry landscape mosaics in 1965 might still affect the spatial species richness distribution of vascular plants, amphibians, reptiles, birds and mammals in 2009 in the province of Barcelona. In their multi-taxon study on the effect of land-use changes on species diversity on formerly grazed dry grasslands in the Central Eastern Alps, Hilpold et al. (2018) showed that larch forests harbor a high number of pasture species even after 30–160 years of abandonment, corroborating

that the localized species richness is not in equilibrium with the surrounding landscape, but heavily influenced by historical land-use patterns many decades after ending the former land use.

Particularly in Europe, there are many regions with ancient land-use activities. As a result of different social-ecological drivers like technological advances, demographic patterns and economic pressures, societal demands, and increasingly, also climate change, more than 50% of the EU27 states area is affected by changes which occurred during the period 1900–2010 (Fuchs et al. 2013) with a dominance of urbanization and land abandonment (Van der Sluis et al. 2018), the latter being an important driver of post-abandonment forest expansions (Plieninger et al. 2016; Bürgi et al. 2017a). Besides climate, topography and seed availability, land use history exerts a strong effect on secondary succession processes leading to afforestation (Tasser et al. 2007). Zimmermann et al. (2010) determined the main spatiotemporal land-use and land-cover change pattern in the last 200 years in the European Alps on the basis of historical maps, and remote sensing data, for 35 municipalities in five alpine countries that were representative of a wide range of the environmental, agro-economic, and political conditions. In the nineteenth century, land-use was quite homogeneous with either grassland farming or mixed farming (grasslands and crops). Up to 2000, more than 50% of the grassland areas have been abandoned, whereas areas with mixed farming underwent a specialization in grassland farming, vine and fruit cultures, or the continuous use of arable fields. These differences in land use history, expressed by a mosaic of former croplands and pastures, have important long-term implications for post-abandonment forest establishment and due to legacy effects of the landscape transition, will also change the landscape pattern in the next decades although land-use change already peaked between 1960s and 1980s.

In summary, there is a large body of literature exploring the role and relevance of legacy effects on landscape pattern, but they focus merely on historical changes in human activities, their interaction with the biophysical systems and the time lags with which these are reflected in a pattern change, but hardly address trajectories of landscape development and the dynamic feedback between important variables of change.

## Processes

Besides affecting patterns, land-use legacies also alter system dynamics and processes (Fraterrigo et al. 2006; Perring et al. 2016). In the last two decades, a considerable effort has been devoted to understanding the effects of (mainly agricultural) legacies on biogeochemical cycles by identifying the mechanisms driving post-agricultural community shifts. Freschet et al. (2014) investigated major transformations of ecosystem properties in an old-growth remote boreal forest in northern Scandinavia, in constant low-intensity use over several centuries by Reindeer-herding Sami. The Sami visited there between 100 and 400 years ago with semi-permanent settlements, transferring organic matter to the settlement areas by humans and reindeer herds, compacting the soil through trampling, using understory vegetation, and selectively cutting pine trees for fuel. Although this use was abandoned 100 years ago, important ecosystem processes remain altered up to the present day. For example, soil microbial activity and nutrient availability close to the settlements increased threefold, leading to a higher primary productivity, higher concentrations of foliar N and P, and a higher litter quantity and quality in the vicinity of the settlements. The increase of soil organic matter cycling and nutrient availability coming from land use many decades ago, triggered a rejuvenation of the ecosystem that is still present. Similarly, Fraterrigo et al. (2005) detected imprints of past land use on nitrogen cycling rates which were significantly lower in historically used Southern Appalachian forest sites (logging and pasturing) than in reference areas. They concluded that these differences were markedly influenced by the biotic processes and historical changes in land use. Such persistent imprints of former agricultural practices on nutrient cycles in terrestrial ecosystems may also exert important functional consequences on food webs. Comparing ancient and post-agricultural alluvial forests in Belgium, Peña et al. (2016) detected that legacy effects strongly affect biotic and abiotic plant–soil feedbacks, which are coupled with herbivory. Hence, understory species in post-agricultural forests suffered markedly greater herbivore pressure than in ancient sites, because of unbalanced plant N:P ratios due to higher soil phosphorus levels. Similarly, Quetier et al. (2007) showed the historical context of management decisions on soil P and N in subalpine



grasslands of Villar d'Arène, comparing never-ploughed hay meadows with former arable fields converted to terraced grasslands, and abandoned grasslands. They concluded that the dynamics of vegetation and ecosystem properties are explained by a combination of long-term successional dynamics over a few decades, interacting with short-term changes in management over a few years. Furthermore, past, and present land use intensity, and the resulting legacies on vegetation and soils, shape ecosystem services supply at the field level. Hence, long term legacies alter ecosystem and landscape services (Egarter Vigl et al. 2016; Ziter et al. 2017). This will be briefly discussed using the example of carbon (C) sequestration, since forest ecosystems play an important role in the global climate system and in a short-term perspective, C-sequestration in vegetation and soils of post-abandonment forests represents a promising strategy to offset carbon emissions (Mackey et al. 2013). Several studies in the European Alps stress how long-lasting effects of historical land-use practices enhance the C sink potential of such forests. Gimmi et al. (2013) showed that forest soils in stands historically affected by long-term litter raking in Switzerland, still show reduced carbon pools up to more than a century after abandonment of this practice. Niedertscheider et al. (2017) analyzed the role of different land-use types and intensities on vegetation carbon stocks in the Austrian central Alps. After a period of agriculturally dominated land-use impacts up to 1954, with massive carbon depletion, polarization into intensification in the lower areas and low-intensity use at higher elevations took place and the carbon stock tripled up to 2003, mainly due to post-abandoned forests. However, the vegetation is still net-accumulating carbon because of multi-decadal effects of land-use changes. To disentangle effects of past land use, natural disturbances, and ongoing climate change in a European forest landscape, Thom et al. (2018) modelled past and future forest dynamics, individually controlling for land use history, the temporal interaction of two disturbance episodes (wind and bark beetles), 90 years apart, and climate change in a factorial simulation study. They found long-lasting legacy effects of both the cessation of historic land use and past natural disturbance on the forest C sink, with the legacy effect of past land use being an order of magnitude stronger than the impact of natural disturbances. Interestingly, the simulation

revealed that the future forest carbon cycle was strongly driven by the cessation of historic land use, while climate change reduced the forest C uptake. Overall, these three studies conclusively show that neglecting legacies can substantially bias assessments of future forest dynamics in the central European mountains. These findings may not hold for other forest systems without century-long land-use histories, as shown by Loudermilk et al. (2013) for a landscape simulation study on carbon dynamics of forests in the Lake Tahoe Basin in North America. In these ecosystems, landscape legacies related to major disturbances dominate the historical land use impacts.

This brief summary of land-use legacy effects on landscape processes shows how important it is to detect the mechanism driving landscape dynamics and addressing ecosystems as complex adaptive systems. Some of the authors also point out that these legacies lead to ecosystems being a trajectory of change e.g. in terms of ecosystem process rates (Fraterrigo et al. 2006; Perring et al 2016). Despite this long-acknowledged evidence of land-use legacies for explaining contemporary landscape function and services a simultaneous focus on the environmental and the social aspects driving these changes and how the ecosystem and the social systems interact is lacking. Landscape ecology is predestined to meet this urgent need for more inter- and transdisciplinary collaboration integrating social and ecological research approaches.

#### Understanding path dependence

Landscapes develop over time, shaped by stand factors, external drivers and legacy effects of past pattern and processes (Fig. 1). To gain more insights into the inherent dynamics of place-specific society-landscape interactions, we propose to adapt a perspective focusing on path dependence of landscape development. A coherent effort for such a focus offers the chance to go beyond gaining insights into mechanisms and constraining factors for one specific development to transferrable insights, which would be extremely beneficial for landscape planning and landscape modelling. The analysis of historical landscape development reveals how current landscapes are the result of development pathways that can be traced through various approaches, promoted using various terminologies. For example, Ernoult et al. (2006)

showed how divergent and convergent developments co-occur, i.e. similar landscapes resulting from different pasts, and different landscapes resulting from similar past conditions. Käyhkö and Skånes (2008) proposed the development of Landscape Change Trajectory Analyses (LCTAs) to go beyond a simple addition of conversion probabilities in studies of land-use and land-cover change, and to also address the underlying dynamics resulting from processes such as succession etc. However, analyzing pathways of landscape change often disclose some puzzling inefficiencies regarding the deliberate management of a landscape in terms of economic and ecological sustainability, and they show landscapes remaining preserved from major alterations for long periods of time. Such observations suggest that some pathways are shaped by processes operating at the level of the whole socio-economic system involved, where e.g. institutional regimes might cause locked-in situations, and not foremost at a land/ecosystem unit level. Zariņa (2013), building on a theoretical framework from historical sociology (Mahoney 2000), illustrates path dependence in the analysis of strip field management practices, resulting in very different developments in the two Latvian villages studied. She underlines that path dependence is relevant beyond being an approach for understanding landscape development, but also due to the traces specific pathways leave in people's attachment to places and practices.

We propose that the application of path dependence, as developed in historical sociology (Mahoney 2000), indeed provides a typology of explanatory linkages, which is worth being translated into a landscape ecological context due to striking analogies between social and ecological systems—analogs which of course have their limitations and have to be addressed with a lot of caution. Path dependence is seen as sequences of causal mechanisms that are characterized by specific degrees of inertia (reproduced practice or reinforced developmental pathway). The study of pathways is therefore suitable to reveal characteristic inefficiencies (economically speaking) and the inability to cast off a pathway and stop practices (socially speaking), in other words, to detect 'lock-in' situations. Mahoney (2000) suggests a distinction between reactive sequences and self-reinforcing sequences. The latter characterize the formation and long-term reproduction of a given institutional pattern that mostly deals with social and cultural

processes, for instance, institutions, norms, practices and customs, which shape landscapes in various forms. Reactive sequences describe chains of temporally ordered and causally connected events, for example, pathways towards abandonment and eventual overgrowth in marginalized areas.

A path-dependent institution can be recognized by its various properties as an eventually inefficient long-term reproduction of an institution (Djelic and Quack 2007), or also by its 'lock-in' effects (Mahoney 2000; Pierson 2000). Wilson (2014), in the context of transitional pathways at the community level, distinguishes four aspects leading to community 'lock-ins', i.e. learned practices, complex stakeholder interactions, lack of willingness for change, and the potentially large impact of small decisions. At landscape level such socially and culturally produced lock-ins might have positive, but more often rather negative effects, especially in terms of ecological sustainability. Although such effects will always have a temporal dimension, the analysis of lock-ins can mark a way for avoiding a negative deterministic outcome. To identify the different mechanisms of lock-ins, Mahoney (2000) proposes four explanatory modes – utilitarian, functional, power, and legitimate explanations, while Wilson (2014) differentiates among structural, economic, and socio-psychological mechanisms of lock-ins. These two approaches have both similarities and specific angles that could be interesting for landscape ecology.

Whereas the study of persistence has received some attention in landscape research (e.g. Lieskovsky and Bürgi 2018), this is, so far, not the case for path dependence, focusing on inertia in the system including not only the persistence of landscape structures or elements, but also the persistence of landscape development and the underlying mechanisms, such as self-reinforcing and reactive sequences (Mahoney 2000—as outlined above). In ecological systems, one can find rather simple analogies of such sequences in successional pathways after stochastic disturbance events, or the development of novel ecosystems due to global change. But complexity is increasing by moving from ecosystems to (cultural-) landscapes, as illustrated in the following example of Latvia's polder landscapes (Zariņa et al. 2018). With the Latvian polders, we do not present, deliberately, an example of one of the societally and ecologically appreciated cultural landscapes (e.g. protected as UNESCO world heritage sites

<http://whc.unesco.org/en/list>), but an example where the often applauded persistence of cultural landscapes is not, as such, positive. In Latvia there are 54 polders which are on average about 1000 ha in size. They were constructed during the specific timeframe of the USSR's productivist ideology in ecologically sensitive locations, i.e. in wetlands adjacent to lakes and rivers so causing agricultural pollution problems for these waterbodies. In the 1990s the ownership of the land was restored to the situation as was during the interwar period, before the construction of the polders, thus recreating an ownership pattern with diverse private, municipal, and state interests. All in all, these polders embody one of the most vulnerable Soviet legacies in terms of agricultural inheritance, environmental problems and contemporary use (Zariņa et al. 2018). Rebuilding the ecological capital in these environmentally sensitive areas would entail a reversal of these pathways, demanding at least a partial deconstruction of polders for restoring the wetlands and adjacent waterbodies, as well as the introduction of a management plan to achieve a balance between the needs of farmers and wetland protection. However, presently, most of these agro-landscapes (mostly croplands, but also permanent and cultivated grasslands) are “locked-in” within institutional reproduction mechanisms that impede changing the development trajectory towards more resilient paths. One of the most important impediments is the ‘mindset’ of farmers and decision-makers that seems to be locked-in into a productivist mode of agricultural production, grounded in the actors’ subjective beliefs about what is appropriate and thus voluntarily opting for its reproduction (legitimation explanation). For many small scale farmers agricultural activities on polder farmlands mean additional income, however the practices are supported mainly by the powerful actors, such as the State (owners of the large infrastructure), municipalities (taxes and the management issues), and large landowners (agricultural business). The mechanisms of change here would entail the strengthening of subordinate groups, such as environmental protection agencies, and the promotion of other use values for people and nature. The utilitarian explanation suggests that the change towards more resilient pathways would occur when it is no longer in the self-interest of actors to reproduce a given institution (Mahoney 2000). Drawing on the logic of the market it would mean increased competitiveness, e.g.

shifting the operational costs of polders to the responsibility of landowners, which would, in turn, mean a re-evaluation of the costs and benefits from an economic point of view.

These transformed wetlands, together with their ecological, social, economic and ideological complexities, nowadays mark a pathway with strong lock-in effects that, according to Wilson (2014), are inherent in the community itself through various factors such as conservatism, lethargic behavior, habits, etc. But of no less importance here is the polder landscape as a whole (functional explanation) with its superstructure of dams, pump stations, and canals, which has existed for many decades, and which has enabled, as a result of reactive path dependent sequences (event chains of “inherent logic”), various derived developments and values, for example, suburban housing, road networks and even nature protection values. However, to overcome, or at least deviate from this pathway, which historically was developed for strengthening economic capital, is paramount for a more sustainable development in such ecologically sensitive areas.

### Putting landscapes and their ecology in a historical context

Present landscapes and ecosystems are shaped by past conditions and their characteristic persistence and susceptibility (i.e. landscape  $t-1$  in Fig. 1) e.g. the effects of external drivers, stand factors and internal processes, which consequently become effective with a specific time-lag. We propose to additionally focus on pathways and path dependence. Realizing how central the consideration of the historical dimension is for landscape ecology inevitably leads to two further, closely linked insights, i.e. the relevance of reference points and of value-based judgements. Analyzing the historical dimensions of landscapes reveals their dynamics, i.e. there is no such thing as a clear and stable reference point for restoration projects, but history provides a sequel of transitional stages, each characterized with a characteristic bundle of landscape services (Zoderer et al. 2019). A high diversity in services, also commonly known as ‘multifunctionality’, is associated to a great landscape heterogeneity (Lavorel et al. 2019; Huber et al. 2020). Such a high diversity of services might also be of high value to



society and worth being aimed at for the future. But the choice of the reference point is inevitably based on our current values as the set of services regarded as relevant and important also reflects our foremost current needs and priorities (Bürgi et al. 2015b; Locatelli et al. 2017). Value-based is also our notion of change.

If landscape ecology wants to contribute to transformation towards sustainability, we have to abandon the notion that persistence is per se positive (a notion which comes along with the concept of traditional cultural landscapes), and change inevitably leads to deterioration. Indeed, landscapes in all parts of the world badly need to be restored into societally and ecologically more desirable states, and landscape ecology has the means and can provide insights contributing to such changes. The proposed perspective of path dependence in studies of landscape development reveals the specific pathways of landscape development, black-boxing the specific ways in which inertia impacts the development trajectories, and enabling the detection of management options. Whereas a certain degree of inertia might well be societally and ecologically desirable, e.g. in the case of “good” landscape resilience, as described by Selman et al. (2012), landscapes might also be stuck in states which are neither societally nor economically or ecologically beneficial. Thus, the analysis of inertia has to be separated from valuation. In cases of undesirable landscape (development) inertia, systematic assessment might allow the determination of leverage points for transformation towards more sustainable development. For example, sometimes it is difficult to cast off ineffective place-based agricultural practices, since agricultural practice itself can be a reproduced institution for many rural inhabitants, based on previous decision-making. Such practices in marginal agricultural areas could be directed towards more sustainable and economically more beneficial agricultural incomes by offering alternatives to change them and readjust to them (e.g. instead of crop cultures in moraine uplands a shift towards extensive livestock farming) thus strengthening socio-ecological resilience. In agro-industrial landscapes the lack of green infrastructure (e.g. semi-natural land uses along rivers, often altered or altogether removed for so-called “melioration projects”, Bürgi et al. 2015a) can be explained simply by way of inertia to expand the tillage by whatever means necessary, that is, following

a pathway which is entrenched in a productivist mindset and follows a strongly economic logic. To overcome this economically driven path dependence (e.g. by ensuring a shift towards permanent grasslands in floodplains) other alternatives should be offered, such as economically adequate agri-environmental schemes.

Thus, recognizing the historical dimension of landscapes is not driven by nostalgia—on the contrary: it enables the present to be put in context, facilitates discussions on societal needs towards landscapes, opens up the view on opportunities for changes towards more sustainable conditions and provides insights into core drivers and leverage points to be targeted for implementing change. We propose that complementing the study of legacy effects on pattern and processes by studies of path dependence of landscape development will help to advanced landscape ecology by addressing the historical, as well as cultural and social dimension of landscapes and ecosystems in a more encompassing way and will allow landscape ecology to raise its impact and relevance in the transformation towards sustainability.

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## References

- Antrop M (2005) Why landscapes of the past are important for the future. *Landscape Urban Plan* 70:21–34
- Arce-Nazario JA (2007) Human landscapes have complex trajectories: reconstructing Peruvian Amazon landscape history from 1948 to 2005. *Landscape Ecol* 22:89–101
- Arthur WB (1989) Competing technologies, increasing returns, and lock-in by historical events. *Econ J* 99:116–131

- Auffret AG, Kimberley A, Plue J, Walden E (2018) Super-regional land-use change and effects on the grassland specialist flora. *Nat Commun* 9:3464
- Britt DW (1993) Metaphors of process: scenarios, trajectories, pathways and routes. *Appl Behav Sci Rev* 1:179–189
- Bürgi M, Gimmi U (2007) Three objectives of historical ecology: the case of litter collecting in Central European forests. *Landscape Ecol* 22:77–87
- Bürgi M, Hersperger AM, Schneeberger N (2004) Driving forces of landscape change—current and new directions. *Landscape Ecol* 19:857–868
- Bürgi M, Salzmann D, Gimmi U (2015a) 264 years of change and persistence in an agrarian landscape: a case study from the Swiss lowlands. *Landscape Ecol* 30:1321–1333
- Bürgi M, Silbernagel J, Wu JG, Kienast F (2015b) Linking ecosystem services with landscape history. *Landscape Ecol* 30:11–20
- Bürgi M, Bieling C, von Hackwitz K, Kizos T, Lieskovsky J, Martin MG, McCarthy S, Muller M, Palang H, Plieninger T, Pritsman A (2017a) Processes and driving forces in changing cultural landscapes across Europe. *Landscape Ecol* 32(11):2097–2112
- Bürgi M, Ostlund L, Mladenoff DJ (2017b) Legacy effects of human land use: ecosystems as time-lagged systems. *Ecosystems* 20:94–103
- Clar E, Pinilla V (2011) Path dependence and the modernisation of agriculture: a case study of Aragon, 1955–85. *Rural Hist* 22:251–269
- Cousins SAO (2009) Landscape history and soil properties affect grassland decline and plant species richness in rural landscapes. *Biol Conserv* 142:2752–2758
- Crumley CL (2007) Historical ecology: integrated thinking at multiple temporal and spatial scales. In: Hornborg A, Crumley CL (eds) *The world system and the earth system: global socioenvironmental change and sustainability since the neolithic*. Left Coast Press, Walnut Creek, pp 15–28
- Cusser S, Neff JL, Jha S (2018) Land-use history drives contemporary pollinator community similarity. *Landscape Ecol* 33:1335–1351
- David PA (1985) Clio and the economics of QWERTY. *Am Econ Rev* 75:332–337
- Djelic ML, Quack S (2007) Overcoming path dependency: path generation in open systems. *Theor Soc* 36:161–186
- Dondina O, Saura S, Bani L, Mateo-Sanchez MCM (2018) Enhancing connectivity in agroecosystems: focus on the best existing corridors or on new pathways? *Landscape Ecol* 33:1741–1756
- du Toit MJ, Kotze DJ, Cilliers SS (2016) Landscape history, time lags and drivers of change: urban natural grassland remnants in Potchefstroom, South Africa. *Landscape Ecol* 31:2133–2150
- Dupouey JL, Dambrine E, Laffite JD, Moares C (2002) Irreversible impact of past land use on forest soils and biodiversity. *Ecology* 83:2978–2984
- Egarterer V, Schirpke U, Tasser E, Tappeiner U (2016) Linking long-term landscape dynamics to the multiple interactions among ecosystem services in the European Alps. *Landscape Ecol* 31:1903–1918
- Ernault A, Freiré-Díaz S, Langlois E, Alard D (2006) Are similar landscapes the result of similar histories? *Landscape Ecol* 21:631–639
- Ewers RM, Didham RK, Pearse WD, Lefebvre V, Rosa IM, Carreiras JM, Lucas RM, Reuman DC (2013) Using landscape history to predict biodiversity patterns in fragmented landscapes. *Ecol Lett* 16(10):1221–1233
- Florenzano A (2019) The history of pastoral activities in Italy inferred from palynology: a long-term perspective to support biodiversity awareness. *Sustainability*. <https://doi.org/10.3390/su11020404>
- Fraterrigo JM, Turner MG, Pearson SM, Dixon P (2005) Effects of past land use on spatial heterogeneity of soil nutrients in southern Appalachian forests. *Ecol Monogr* 75:215–230
- Fraterrigo JM, Turner MG, Pearson SM (2006) Interactions between past land use, life-history traits and understory spatial heterogeneity. *Landscape Ecol* 21:777–790
- Freschet GT, Ostlund L, Kichenin E, Wardle DA (2014) Aboveground and belowground legacies of native Sami land use on boreal forest in northern Sweden 100 years after abandonment. *Ecology* 95:963–977
- Fuchs R, Herold M, Verburg PH, Clevers JGPW (2013) A high-resolution and harmonized model approach for reconstructing and analysing historic land changes in Europe. *Biogeosciences* 10:1543–1559
- Geist HJ, Lambin EF (2002) Proximate causes and underlying driving forces of tropical deforestation. *Bioscience* 52:143–150
- Gimmi U, Poulter B, Wolf A, Portner H, Weber P, Bürgi M (2013) Soil carbon pools in Swiss forests show legacy effects from historic forest litter raking. *Landscape Ecol* 28:835–846
- Goldstone JA (1998) Initial conditions, general laws, path dependence, and explanation in historical sociology. *Am J Sociol* 104:829–845
- Hilpold A, Seeber J, Fontana V, Niedrist G, Rief A, Steinwandter M, Tasser E, Tappeiner U (2018) Decline of rare and specialist species across multiple taxonomic groups after grassland intensification and abandonment. *Biodivers Conserv* 27:3729–3744
- Huber L, Schirpke U, Marsoner T, Tasser E, Leitinger G (2020) Does socioeconomic diversification enhance multifunctionality of mountain landscapes? *Ecosyst Serv* 44:101122
- Jackson ST, Sax DF (2010) Balancing biodiversity in a changing environment: extinction debt, immigration credit and species turnover. *Trends Ecol Evol* 25:153–160
- Käyhkö N, Skånes H (2008) Retrospective land cover/land use change trajectories as drivers behind the local distribution and abundance patterns of oaks in south-western Finland. *Landscape Urban Plan* 88:12–22
- Kirk EA, Reeves AD, Blackstock KL (2007) Path dependency and the implementation of environmental regulation. *Environ Plann C* 25:250–268
- Kolen J, Renes J (2015) Landscape biographies: key issues. In: Kolen J, Renes J, Hermans R (eds) *Landscape biographies*. Amsterdam University Press, Amsterdam
- Kuussaari M, Bommarco R, Heikkinen RK, Helm A, Krauss J, Lindborg R, Ockinger E, Partel M, Pino J, Roda F, Stefanescu C, Teder T, Zobel M, Steffan-Dewenter I (2009) Extinction debt: a challenge for biodiversity conservation. *Trends Ecol Evol* 24(10):564–571
- Lavorel S, Grigulis K, Leitinger G, Kohler M, Schirpke U, Tappeiner U (2019) Historical trajectories in land use

- pattern and grassland ecosystem services in two European alpine landscapes. *Reg Environ Change* 17:2251–2264
- Levin K, Cashore B, Bernstein S, Auld G (2009) Playing it forward: Path dependency, progressive incrementalism, and the “Super Wicked” problem of global climate change. *IOP Conference Series: Earth and Environmental Science*, vol 6, pp 502002
- Li L, Fassnacht FE, Storch I, Bürgi M (2017) Land-use regime shift triggered the recent degradation of alpine pastures in Nyanpo Yutse of the eastern Qinghai-Tibetan Plateau. *Landsc Ecol* 32:2187–2203
- Libecap GD (2009) Second-degree Path Dependence: Information Costs, Political Objectives, and Inappropriate Small-farm Settlement of the North American Great Plains. In: Magnusson L, Ottosson J (eds) *The Evolution of Path Dependence*, chap 2. Edward Elgar Publishing, UK
- Lieskovsky J, Bürgi M (2018) Persistence in cultural landscapes: a pan-European analysis. *Reg Environ Change* 18:175–187
- Locatelli B, Lavorel S, Sloan S, Tappeiner U, Geneletti D (2017) Characteristic trajectories of ecosystem services in mountains. *Front Ecol Environ* 15:150–159
- Loran C, Kienast F, Bürgi M (2018) Change and persistence: exploring the driving forces of long-term forest cover dynamics in the Swiss lowlands. *Eur J Forest Res* 137:693–706
- Loudermilk EL, Scheller RM, Weisberg PJ, Yang J, Dilts TE, Karam SL, Skinner C (2013) Carbon dynamics in the future forest: the importance of long-term successional legacy and climate-fire interactions. *Glob Chang Biol* 19:3502–3515
- Mackey B, Prentice IC, Steffen W, House JI, Lindenmayer D, Keith H, Berry S (2013) Untangling the confusion around land carbon science and climate change mitigation policy. *Nat Clim Change* 3:552–557
- Mahoney J (2000) Path dependence in historical sociology. *Theor Soc* 29:507–548
- Martínez-Harms MJ, Balvanera P (2012) Methods for mapping ecosystem service supply: a review. *Int J Biodiver Sci Ecosyst Serv Manag* 8:17–25
- Metzger JP, Martensen AC, Dixo M, Bernacci LC, Ribeiro MC, Teixeira AMG, Pardini R (2009) Time-lag in biological responses to landscape changes in a highly dynamic Atlantic forest region. *Biol Conserv* 142:1166–1177
- Miyasaka T, Le Q, Okuro T, Zhao XY, Takeuchi K (2017) Agent-based modeling of complex social-ecological feedback loops to assess multi-dimensional trade-offs in dry-land ecosystem services. *Landsc Ecol* 32:707–727
- Monger C, Sala OE, Duniway MC, Goldfus H, Meir IA, Poch RM, Throop HL, Vivoni ER (2015) Legacy effects in linked ecological-soil-geomorphic systems of drylands. *Front Ecol Environ* 13(1):13–19
- Niedertscheider M, Tasser E, Patek M, Rudisser J, Tappeiner U, Erb KH (2017) Influence of land-use intensification on vegetation C-stocks in an Alpine Valley from 1865 to 2003. *Ecosystems* 20:1391–1406
- Palang H, Kulvik M, Printsman A, Storie JT (2019) Revisiting futures: integrating culture, care and time in landscapes. *Landsc Ecol* 34:1807–1823
- Peña E, Baeten L, Steel H, Víaene N, De Sutter N, De Schrijver A, Verheyen K, Bailey J (2016) Beyond plant–soil feedbacks: mechanisms driving plant community shifts due to land-use legacies in post-agricultural forests. *Funct Ecol* 30(7):1073–1085
- Perring MP, De Frenne P, Baeten L, Maes SL, Depauw L, Blondeel H, Caron MM, Verheyen K (2016) Global environmental change effects on ecosystems: the importance of land-use legacies. *Glob Chang Biol* 22(4):1361–1371
- Pierson P (2000) Increasing returns, path dependence, and the study of politics. *Am Polit Sci Rev* 94:251–267
- Plieninger T, Draux H, Fagerholm N, Bieling C, Burgi M, Kizos T, Kuemmerle T, Primdahl J, Verburg PH (2016) The driving forces of landscape change in Europe: a systematic review of the evidence. *Land Use Policy* 57:204–214
- Quetier F, Thebault A, Lavorel S (2007) Plant traits in a state and transition framework as markers of ecosystem response to land-use change. *Ecol Monogr* 77:33–52
- Rhemtulla JM, Mladenoff DJ (2007) Why history matters in landscape ecology. *Landsc Ecol* 22:1–3
- Rhemtulla JM, Mladenoff DJ, Clayton MK (2009) Legacies of historical land use on regional forest composition and structure in Wisconsin, USA (mid-1800s-1930s-2000s). *Ecol Appl* 19:1061–1078
- Schirpke U, Leitinger G, Tasser E, Rüdiger J, Fontana V, Tappeiner U (2020) Functional spatial units are fundamental for modelling ecosystem services in mountain regions. *Appl Geogr* 118:102200
- Schrama M, Vandecasteele B, Carvalho S, Muylle H, van der Putten WH (2016) Effects of first- and second-generation bioenergy crops on soil processes and legacy effects on a subsequent crop. *Gcb Bioenerg* 8:136–147
- Scott P (2006) Path dependence, fragmented property rights and the slow diffusion of high throughput technologies in inter-war British coal mining. *Bus Hist* 48:20–42
- Selman P, Plieninger T, Bieling C (2012) Landscapes as integrating frameworks for human, environmental and policy processes. In: Bieling C, Plieninger T (eds) *Resilience and the Cultural Landscape*. Cambridge University Press, Cambridge, pp 27–48
- Szabó P (2015) Historical ecology: past, present and future. *Biol Rev* 90:997–1014
- Tasser E, Walde J, Tappeiner U, Teutsch A, Noggler W (2007) Land-use changes and natural reforestation in the Eastern Central Alps. *Agr Ecosyst Environ* 118:115–129
- Tello E, Marull J, Padró R, Cattaneo C, Coll F (2020) The loss of landscape ecological functionality in the Barcelona Province (1956–2009): could land-use history involve a legacy for current biodiversity? *Sustainability*. <https://doi.org/10.3390/su12062238>
- Thom D, Rammer W, Garstener R, Seidl R (2018) Legacies of past land use have a stronger effect on forest carbon exchange than future climate change in a temperate forest landscape. *Biogeosciences* 15:5699–5713
- Tracy JL, Kantola T, Baum KA, Coulson RN (2019) Modeling fall migration pathways and spatially identifying potential migratory hazards for the eastern monarch butterfly. *Landsc Ecol* 34:443–458
- Turner MG (1989) Landscape ecology—the effect of pattern on process. *Annu Rev Ecol Syst* 20:171–197
- Turner MG (2005) Landscape ecology: what is the state of the science? *Annu Rev Ecol Syst* 36:319–344

- Turner MG, Gardner RH, O'Neill RV (2003) *Landscape ecology in theory and practice: pattern and process*. Springer, New York
- van Buuren A, Ellen GJ, Warner JF (2016) Path-dependency and policy learning in the Dutch delta: toward more resilient flood risk management in the Netherlands? *Ecol Soc*. <https://doi.org/10.5751/Es-08765-210443>
- Van der Sluis T, Pedroli B, Frederiksen P, Kristensen SBP, Busck AG, Pavlis V, Cosor GL (2018) The impact of European landscape transitions on the provision of landscape services: an explorative study using six cases of rural land change. *Landsc Ecol* 34:307–323
- Virah-Sawmy M, Gillson L, Gardner CJ, Anderson A, Clark G, Haberle S (2016) A landscape vulnerability framework for identifying integrated conservation and adaptation pathways to climate change: the case of Madagascar's spiny forest. *Landsc Ecol* 31:637–654
- Walters BB (2017) Explaining rural land use change and reforestation: a causal-historical approach. *Land Use Policy* 67:608–624
- Wilson GA (2014) Community resilience: path dependency, lock-in effects and transitional ruptures. *J Environ Plann Man* 57:1–26
- Yona L, Cashore B, Schmitz OJ (2019) Integrating policy and ecology systems to achieve path dependent climate solutions. *Environ Sci Policy* 98:54–60
- Zariņa A (2013) Path dependence and landscape: initial conditions, contingency and sequences of events in Latgale, Latvia. *Geogr Ann B* 95:355–373
- Zariņa A, Vinogradovs I, Skinkis P (2018) Towards (dis)continuity of agricultural wetlands: Latvia's polder landscapes after Soviet productivism. *Landsc Res* 43:455–469
- Zimmermann P, Tasser E, Leitinger G, Tappeiner U (2010) Effects of land-use and land-cover pattern on landscape-scale biodiversity in the European Alps. *Agr Ecosyst Environ* 139:13–22
- Ziter C, Graves RA, Turner MG (2017) How do land-use legacies affect ecosystem services in United States cultural landscapes? *Landsc Ecol* 32:2205–2218
- Zoderer BM, Tasser E, Carver S, Tappeiner U (2019) Stakeholder perspectives on ecosystem service supply and ecosystem service demand bundles. *Ecosyst Serv* 37:100938

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