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ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ylan20

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To cite this article: Nurdan Erdoğan, Francesco Carrer, Ebru Ersoy Tonyaloğlu, Betül Çavdar, Günder Varinlioğlu, Tevfik Emre Şerifoğlu, Mark Jackson, Kübra Kurtsan, Engin Nurlu & Sam Turner (2020) Simulating Change in Cultural Landscapes: The Integration of Historic Landscape Characterisation and Computer Modelling, Landscapes, 21:2, 168-182, DOI: 10.1080/14662035.2021.1964767

To link to this article: https://doi.org/10.1080/14662035.2021.1964767

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Published online: 07 Dec 2021.

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LANDSCAPES
2020, VOL. 21, NO. 2, 168–182
https://doi.org/10.1080/14662035.2021.1964767

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Simulating Change in Cultural Landscapes: The Integration of Historic Landscape Characterisation and Computer Modelling

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ABSTRACT

More than 80 per cent of the world's landscapes are influenced significantly by human activities, and current land-use and land cover trends are likely to increase the rate of landscape change at a significant rate in the near future. To manage and guide landscape change, and an advocacy of positive landscape change – rather than attempts to stop change as in traditional preservationist approaches – requires the identification of threats and opportunities. Tools to do this will need to be based on well-investigated evidence for the long-term past evolution of landscapes and the understanding of possible future scenarios for change. Historic landscape characterisation (HLC) is a GIS-based method employed to interpret and study landscapes with a particular focus on representing and mapping the aspects of landscape character which result from past cultural processes. This paper introduces a new protocol which uses HLC data to model future landscape evolution and to simulate scenarios of landscape change. It describes a computer-based simulation framework derived from landscape ecology and used with HLC datasets during research on a region in southern Turkey. Such integrated modelling protocols have the potential to assist landscape planners to develop holistic and informative approaches to managing landscape change.

KEYWORDS

Cultural landscapes; historic landscape characterisation; simulation; computer modelling; Turkey

Introduction

Landscapes reflect the long-term interactions between people and their natural environment, indicating that landscapes have been shaped over time through processes that link human needs with natural resources in specific topographical and spatial settings (Bürgi

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et al. 2015). According to the widely cited definition given in the European Landscape Convention (ELC), landscape is 'an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors' (Council of Europe 2000). Both natural conditions and human needs change over time (Antrop 1998), and landscapes change accordingly.

Based on this definition, it can be argued that change is an inherent characteristic of every landscape (Bürgi *et al.* 2004). However, today's landscapes are being transformed at an unprecedented rate and landscape change is often associated with negative outcomes not only for biodiversity and climate, but also for human well-being (Antrop 2005; Bürgi *et al.* 2015). Over the next 20 years, the rate of landscape change is likely to increase across Europe and around the world, triggered by driving forces such as globalisation, urbanisation or land-use intensification. There is an urgent requirement for new tools and methods that can support more sensitive and contextually specific landscape planning and management strategies (Clark *et al.* 2004), including a widely recognised need to promote more effective citizen participation in line with the ELC (e.g. DAHG 2015; Dessein *et al.* 2015).

The goal of this paper is to introduce the concept of 'historic landscape modelling', a new protocol which uses historic landscape characterisation (HLC) data as the basis for modelling the potential evolution of historic landscapes and simulating future scenarios of landscape change. The object of this method is to promote more effective tools for planning which take account of historic character and heritage-related aspects of landscapes, including the encouragement of better-informed public participation in the planning process. Rather than providing a technical discussion of the computer modelling techniques which lie behind the protocol, this short paper gives a theoretical justification and explains the methodological background which led to the development of the model.

Approaches

Land-use and land-cover modelling

Landscape change is a complex, dynamic process that involves physical aspects (such as geology, soils, climate and vegetation) as well as economic, social and cultural factors within a given chronological and spatial framework. The success of landscape planning depends on understanding the interrelationships between complex processes which link such factors and their cause–effect relationships. Landscape ecologists make use of algorithms to integrate the 'drivers' of change and simulate future transformations of land-use and land cover. This method builds on a solid understanding of ecosystem changes and their effects and assumes that land-use/cover changes (LUCc) are correlated to changes in landscape structure and function; hence, the analysis of LUCc contributes to understanding changes in landscape patterns (Nagendra *et al.* 2004; Dadashpoor *et al.* 2019).

LUCc modelling, which has been rapidly evolving in recent years, is one of the most important tools for analysing the consequences of land-use change, including prediction of future land-use/cover patterns. Such models are useful for disentangling the complex socio-economic and biophysical forces that influence the rate and spatial pattern of land-use changes and for estimating the future impact of these changes, as

well as informing development of solutions and mitigations (Verburg *et al.* 2004; Erdoğan *et al.* 2011). They include the use of artificial representations of the interactions with the land-use system to explore its dynamics and possible future developments (Lambin *et al.* 2008).

Recent overviews of these simulation models show an increase in the number of models and applications (Mas *et al.* 2014; Ren *et al.* 2019) which address different scales and research questions (Lambin *et al.* 2008). Although the modelling community has a sound understanding of the issues associated with land use modelling (such as modelling theory, model calibration and model application), little attention has been paid so far to the historical dimensions of land use, particularly the influences which historic and cultural factors continue to exert on dynamic landscape patterns and characteristics (Liu and Andersson 2004).

Landscape character

LUCc modelling relies primarily on machine-learning or expert-knowledge based classifications of satellite imagery. Typically, the continuous variation of plant associations is categorised according to a predefined number of land-cover classes. Since satellite imagery is widely available for recent decades, starting from the 1970s, different land-cover maps can be created to investigate the evolution of vegetation and to infer the influence of different driving forces on this evolution. This, in turn, provides the background data and knowledge to develop simulation scenarios and model future LUCc.

The rationale behind the categorisation used in LUCc is that the spatial and relational complexity of land-cover needs to be compressed into a series of standardised classes in order to be utilised for explorative analysis and modelling (Veldkamp and Lambin 2001). A similar rationale led to the development of Landscape Character Assessment (LCA), a method that considers both ecological and cultural aspects of the landscape. Based on their spatial correlation, LCA divides the landscape into areas or regions with uniform and distinctive 'character'; for this purpose, LCA tends to rely on the expertise of a landscape specialist (Butler and Berglund 2014). Although in theory LCA should include the historic dimension of landscape character (Tudor 2014), in practice it usually tends to focus on the current landscape and does not interpret historic changes in sufficient depth or at appropriate scales (Fairclough and Herring 2016). The compression of spatial complexity is therefore comparable to land-cover classification, but the temporal dimension is largely absent from LCA. It is worth noting that the similar problems also affect some other land-cover classification methods, such as the UK National Vegetation Classification (Rodwell 2006).

The work of landscape archaeologists and historians has demonstrated the great extent to which the current character of landscapes depends on their long-term history, with many landscapes still showing signs of human interventions dating back hundreds or even thousands of years (Herring *et al.* 2016; Lyons *et al.* 2016). Addressing the historical dimension alongside the cultural dimension of the landscape is therefore of paramount importance to fully understand their formation and, in turn, to infer the likely pathways of their future development.

Historic landscape characterisation (HLC)

In Britain there is a long tradition of rural history and landscape history which has shown how the distinctive character of many landscapes has been shaped by prehistoric, medieval and modern processes (Johnson 2007; Bowden and McOmish 2011). Historic Landscape Characterisation (HLC) was developed in England in the 1990s in order to map interpretations of how past processes have shaped the character of today's landscapes (Herring 2009; Fairclough and Herring 2016). In the last decade, HLC has begun to be used outside the UK, with new HLC projects in Europe and across the Mediterranean region (Turner and Crow 2010; Bolós *et al.* 2016).

HLC differs from many traditional approaches to landscape archaeology because it is an holistic, generalising method. Rather than relying on the identification of individual features and analysis of relationships between them, HLC attempts to interpret the broader historic patterns across whole landscapes, leaving no gaps without interpretation. In this respect HLC is similar to LCA, which also provides an interpretation of the whole territory under consideration. However, whereas LCA tends to define areas whose distinctive characteristics make each one unique in comparison to the others, HLC uses a defined and limited number of 'HLC types' to identify areas of land whose character has been shaped by similar and recognisable historic processes (Turner 2018). Each HLC project therefore identifies many separate blocks of historic character but only uses a limited number of character types. In this way, HLC simplifies the complexity of landscape evolution to enable investigation of past (and potentially future) trajectories of landscape change (Turner 2006).

In HLC, historical and modern cartographic resources (maps, aerial photographs, etc.) are used to identify areas with common characteristics which result from shared processes in the past. Each area is then associated with a specific character type for every chronological phase considered (as far back as can be established based on the sources available) (Dabaut and Carrer 2021). The size of each region and the number of chronological phases can vary, as they depend on the accessible cartography as well as on the objectives of the characterisation project. The creation of spatially and temporally discrete regions is similar to the automatic detection of land-use/cover classes from satellite imagery. HLC and LUCc datasets are therefore visually comparable, with the most obvious difference being that HLC tends to have a higher spatial and temporal resolution. Based on these observations, it seemed worth assessing whether modelling protocols used for LUCc could also be used for HLC. If successful, the simulation of historic landscape character change might not only increase the resolution of traditional modelling approaches but could also promote the incorporation of cultural and historical values into future landscape scenarios designed to inform public debate about landscape change. The method could therefore provide a valuable addition to the toolkit and data available to landscape planners when they are seeking to evaluate options for the future.

Modelling landscapes

As noted above, a key problem in landscape modelling is how to incorporate historical and cultural processes effectively (Ridding *et al.* 2020). The ecological and cultural patterns in landscapes are constantly changing, and the vectors of change vary over many spatial and time scales. Analyses of land use/cover tend to neglect or ignore the particular

ways human activities have shaped the character of landscapes and consequently do not explain the whole variability of landscape change. For instance, conversion of an extensive open field system to an enclosed system with intensive cultivation is unlikely to be detected in traditional landscape modelling, since both types of fields would be included in an ecological category of 'arable land'. Ignoring the historical and cultural dimension of landscape change is potentially risky from a conservation or management standpoint. Landscapes are inherently dynamic systems, with important ecosystem processes and disturbance regimes operating at many scales and spanning decades, centuries or even millennia (With 2007); they are likely to be affected significantly by changing patterns of cultivation and land-use. The potential of using HLC data to bring the dimension of historic character into landscape modelling will be examined in the following paragraphs.

Simulating future landscape character change

As part of the Newton-Tubitak funded project 'CHiLaT', a collaboration of numerous scholars from British and Turkish universities, a new methodological protocol was developed to model the evolution of historic landscapes and simulate future scenarios of cultural landscape change. A computer-based simulation framework, derived from landscape ecology, was implemented using HLC as the reference dataset. After a thorough assessment of the main machine-learning techniques used in LUCc modelling, a regression-based approach was selected as the most appropriate method for the specific purposes of this research (Atak *et al.* 2014).

Because changes in land-cover and changes in landscape character are conceptually different, the methodologies borrowed from landscape ecology had to be adapted to the nature of HLC datasets, and the strengths and limitations of the resulting protocol had to be evaluated. Dependent variables for the regression were the HLC types. Binary maps were produced for each type, and randomly sampled pixels for each map were used as training samples. Social, economic and ecological drivers of change were considered as predictors of HLC type change, and their influence on the spatial and temporal variation of landscape character was analysed and modelled. The 'suitability to change' of the different landscape character types was addressed through spatial statistics, in order to identify those components of historic landscapes that are less affected by the drivers identified. This protocol was implemented using different GIS software and model frameworks, principally ArcGIS, TerrSet, R, GRASS and Dyna-CLUE. A technical description of this modelling protocol, which has been identified as Historic Landscape Modelling (HLM), will be published in a specialised journal alongside the first outcomes and preliminary assessments. An overview of the preliminary results is presented below.

Historic landscape modelling (HLM) in the Göksu valley

An HLC dataset created during the CHiLaT project for the lower Göksu valley in Turkey was identified as well-suited for testing this novel methodology, since it includes a detailed characterisation of critical changes in the rural landscape which occurred during the second half of the twentieth century (Figure 1). The area is located in the eastern part of southern Turkey's Mediterranean region and has a very diverse landscape, with delta, mountain and river ecosystems (Figure 2). It represents one of the main land

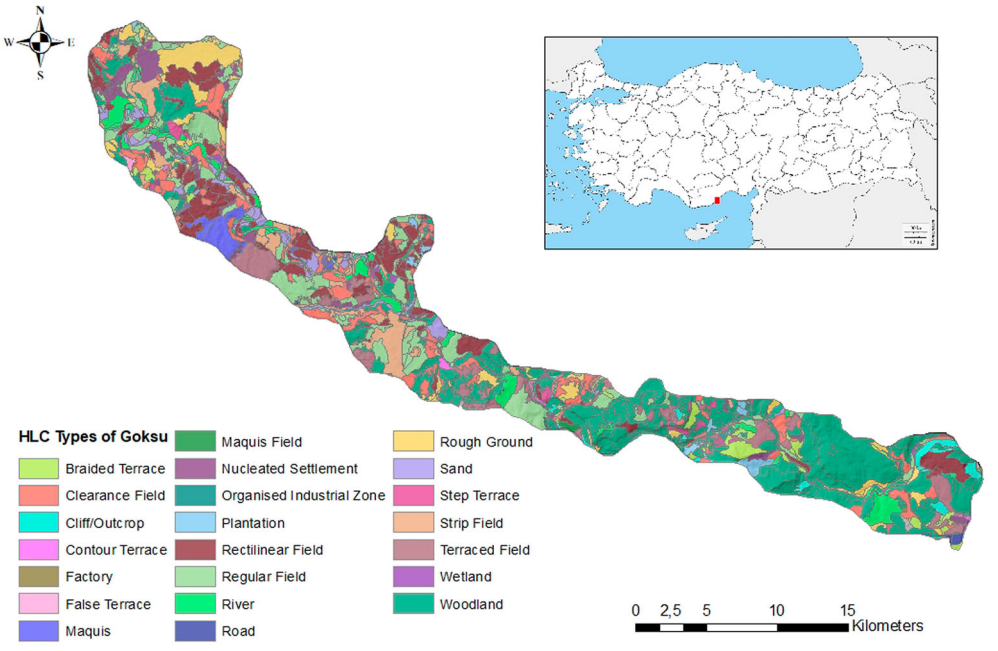


Figure 1. The HLC of the Goksu River valley. Inset: location of the valley in South-Eastern Turkey. Source: McCord Centre for Landscape, Newcastle University; Layout: Nurdan Erdoğan.



Figure 2. Examples of the landscape character types around the Göksu River valley. Top-left and bottom-right: maquis in the foreground and clearance field in the background. Top-right: terraces and plantations. Bottom-left: forest (mountain slope) and rectilinear fields (in the valley bottom). Photo: Francesco Carrer.

routes that connect central Anatolia to the Mediterranean coast of Turkey, and its strategic importance contributed to the intensive occupation of the valley since the Neolithic period (Mac Sweeney and Şerifoğlu 2017). The mild microclimate of the Göksu River valley has fostered the emergence of a remarkable biodiversity (especially wild flora and fauna) and more recently the development of intensive irrigated agriculture in the valley floor.

Twenty-two character types were identified for the territory of the Göksu River valley, and mapped in the HLC geodatabase (Table 1). Aerial photos from the 1950s, 1970s, 1990s and 2010s enable the diachronic evolution of these character types to be mapped. Unfortunately, the Dyna-CLUE software, used in this first test to implement the landscape character simulation, operates with a maximum of ten classes. This is an inherent constraint of the modelling framework, rather than the software, and required the 22 character types to be aggregated into 8 character 'classes', based on similar land-management practices and similar correlation with socio-economic and environmental drivers. Although this simplification might reduce the effectiveness of the model and increase its variance and uncertainty, it is worth pointing out that any other modelling approach would require some compression of landscape diversity (Robinson *et al.* 2018).

The second step was the investigation of the key spatial drivers underlying the landscape structure. A small number of covariates, as simplified proxies of human interaction

Table 1.

Class	Broad type	Definition of broad type
Communication	Road	Large roads, including embankments and service areas as well as bridged
Field	Clearance Field	Small fields with irregular and sinuous boundaries, cut in woodland or maquis
	Maquis Field	Fragmented and irregular fields in large areas of maquis
	Rectilinear Field	Straight-sided fields, usually rectangular or sub-rectangular in shape, created by modern agricultural methods
	Regular Field	Sub-rectangular fields, normally located in coherent blocks of repeated patterns
	Strip Field	Narrow and long fields which are adjacent to each other
Industrial	Factory	Industrial production centres, often related to agriculture
	Organised Industrial Zone	Industrial estate
Rough Ground	Cliff/Outcrop	Steep, rocky ground on remote hillsides (often occurring in relatively small patches)
	Maquis	Rocky ground with small scrub bushes and occasionally trees, historically used for rough pasture
	Plantation	Zones with deliberately planted conifers, nursery or memorial forests
	Rough Ground	Uncultivated lands without maquis vegetation, often reflects areas cleared from woodland or forest
	Sand	Sandy areas along the seashore, transitional zones between the seas and the land
	Wetland	Area of land that is either covered by water or saturated with water
	Woodland	Deciduous and coniferous woodlands, encompassing natural and semi-natural forest
Settlement	Nucleated Settlement	Building together around a core and seasonal resorts
Terrace	Braided Terrace	Terraces joined by switchbacks at the end, to enable the animals to move between the terraces
	Contour Terrace	Terraces that follow topographic contour lines on the slopes
	False Terrace	Modern terraces created by bulldozing, they tend to erase previous landscape character types
	Step Terrace	Straight parallel lines made of stone-built walls
	Terraced Field	Broad terraces built on steep slopes for creating flat fields
Water Source	River	Rivers that flow through the study area, the width of river is over 2 meters

with the environment, were chosen as predictors for the logistic regression. These selected covariates were: aspect, distance from the main cities of the region, elevation, solar radiation, distance from the river Göksu, distance from the main roads, slope, distance from villages. Different regression models were produced for each of the eight landscape character 'classes' (Figure 3). The results show that the spatial variability of these classes is only partially explained by these covariates: other relevant covariates might include factors such as land ownership, accessibility or rainfall. However, the temporal stability of the covariates used and their association with some of the most significant land-management

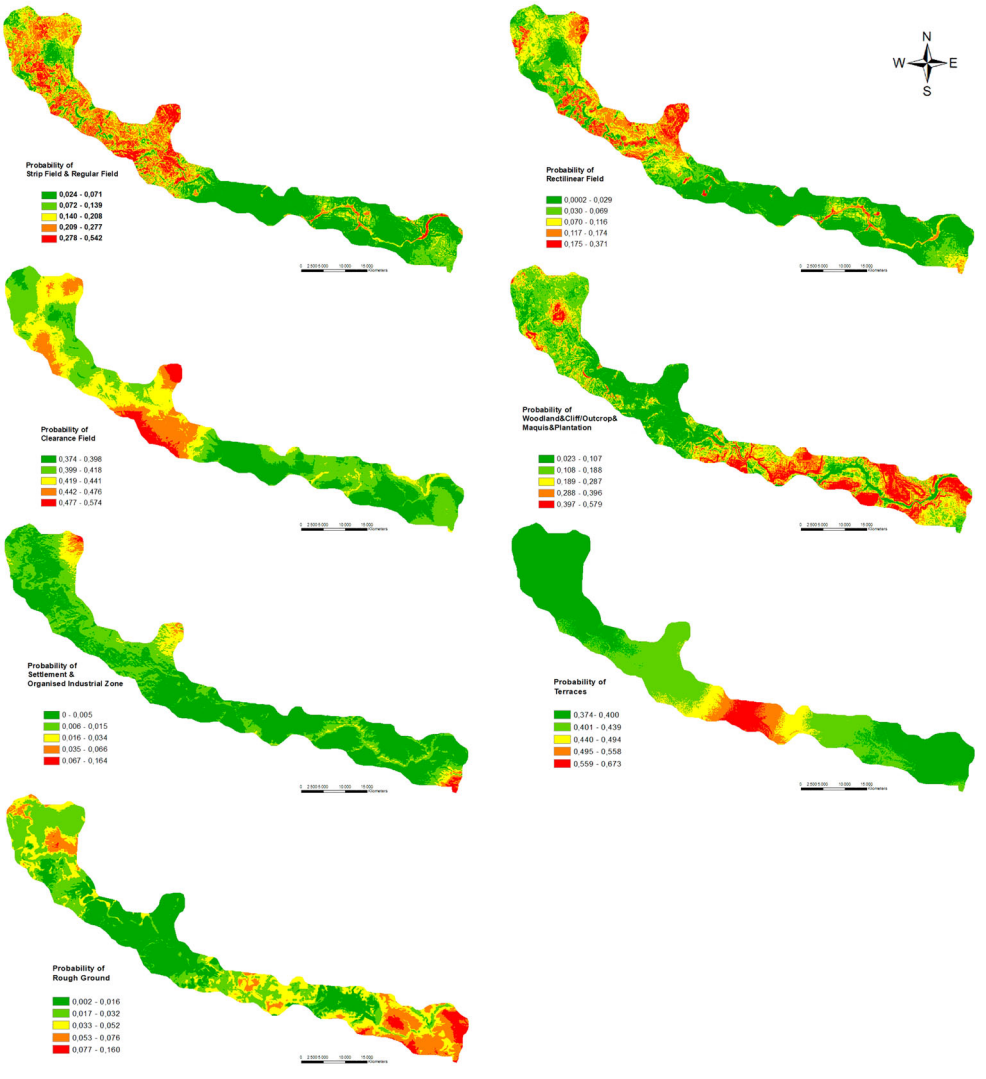


Figure 3. Probability maps for each HLC class derived from logistic regression. The map values represent the probability (0–1) of each pixel to be an HLC class, based on the spatial distribution and variability of selected covariates: aspect, distance from the main cities of the region, elevation, solar radiation, distance from the river Goksu, distance from the main roads, slope, distance from villages. Source: Nurdan Erdoğan.

processes which have occurred in the region (e.g. agriculture intensification, industrialisation) suggest that they represent reliable factors to be tested through scenario simulation.

The results of regression models also suggest that some of the character types used for the HLC in the area might in fact be the result of different processes. The weak correlation of the selected covariates with the spatial distribution of 'clearance fields' and 'rough ground' can be tentatively justified by the fact that these classes are not inherently uniform and might be influenced by different drivers in different ways. This is particularly interesting, since these 2 classes are not the result of the data aggregation described above, but they are 2 of the 22 original HLC types, and they have not been merged with any other type. The HLC type 'rough ground' is the result of different anthropogenic and natural processes (from bulldozing to landslide), whereas clearance fields' can be associated with different farming practices (from new clearance to semi-abandoned grazing land). This lack of formality and homogeneity in the definition of character types affects probability allocation and the results of the simulation.

The final step of the protocol was the simulation of landscape change between the 1990s and the 2010s, based on the results of logistic regression (see above). The outputs of this simulation were validated against the actual HLC for 2010 in order to assess the accuracy of predictions. Considering the methodological issues outlined above the first iteration of HLM yielded promising results, as the 'business-as-usual' scenario between 1990 and 2010 matches reasonably well the HLC of the area for 2010. A 40-year simulation (2010–2050) suggests that, if the same socio-economic forces that have transformed the landscape in the last decades carry on in the future, more historic landscape types will be lost through conversion to intensive monocultures or industrial areas. Recent adjustments to the model have enhanced the importance of neighbouring relationships between character 'classes', thus improving the reliability of future simulation. The next step will be to simulate alternative future scenarios of landscape character change.

Discussion and future challenges

The importance of understanding landscape change and the complexity of landscape requires us to develop more theoretically sound and methodologically sophisticated approaches. Computer modelling has proved to be of great importance for land-use simulation but lacks a historical and cultural perspective. We suggest that the integration of modelling approaches and HLC presents a key opportunity for quantitative landscapes studies, as it would provide a new platform for scholars and policymakers to test different landscape change scenarios.

Nevertheless, our tests showed that some technical obstacles remain to be overcome. In most cases, HLC is produced using high-resolution cartographic sources with the aim of mapping and describing local landscape diversity. It provides a tool for understanding and managing change within the cultural landscape, for identifying what is vulnerable, and for maintaining diversity and distinctiveness in the local scene (Clark *et al.* 2004). HLCs tend to be executed at quite a detailed resolution, leading to the implementation of characterisations which include a large number of character types to account for the complex variability of the historic landscape. Most of the landscape models used commonly in landscape ecology are however only capable of managing a relatively limited number of landscape character types at once. In order to make HLC compatible with

currently available modelling protocols, HLC types have to be aggregated, which results in loss of information and diversity. This limitation has the effect of reducing the capacity of the model to measure and evaluate resilience based on landscape diversity.

Another issue is related to the often-informal approach to the definition of character types in HLC projects (for example the ambiguity of the concept of 'rough ground' in the Göksu HLC). In order to be used for modelling purposes, character types need to be consistent across the study area, which means that each type should be clearly distinguishable. If these preconditions are not met, it can be difficult for the algorithm to find significant correlation between changes in character types and specific driving forces.

In order to promote the development of HLM approaches, future HLCs may need to be designed in ways that can overcome the aforementioned limitations. For example, relevant 'classes' could be used to aggregate 'types' (e.g. Lambrick *et al.* 2013, 84; Watson and Dixon 2018), and the identification of character types could be formalised more rigorously in methodologies. These adjustments could yield significant benefits in terms of strengthening the integration of computational methods in this field of landscape research.

The potential of Historic Landscape Modelling (HLM)

Landscape history and cultural values are at the core of HLC, thereby enabling the heritage and time-depth dimension of landscape to be more generally embedded in spatial planning practices (Dobson and Selman 2012). Nevertheless, cultural heritage (including HLC) tends to have weak integration with ecological and environmental approaches which, by contrast, are themselves relatively well-incorporated into international scientific policy (Fuller *et al.* 2017; Marcucci 2000; Rockman and Hritz 2020). As a result, the historic value of cultural landscapes remains to be fully recognised in many regions for the purposes of planning and management. HLM could provide an interdisciplinary tool which integrates new data, methods and theoretical perspectives to promote research on historic landscapes and foster the management of present and future landscapes as cultural heritage.

Although HLC presents valuable interpretations about historic processes and their consequences for landscape character, it currently includes only limited information about the relationships between cultural processes and the ecological aspects of landscapes. There is a need for further studies to understand how changing ecologies have shaped historic character and indeed to evaluate how changes in historic character may affect future ecological processes. As a common language or approach linking landscape ecology and landscape history, HLM could make a significant contribution to understanding the relationships between ecological and cultural dynamics through the formal identification and quantitative analysis of spatial and non-spatial drivers. To achieve this goal, however, the base data from HLC will need to be enriched by deeper interdisciplinary collaboration which enables more information about the landscape ecology of different HLC types to be included.

HLM could provide an effective platform to discuss desirable and undesirable scenarios of landscape transformation as part of the process of landscape planning. Hypothetical scenarios for simulation can be designed by modelling experts working alongside relevant stakeholders such as policymakers and community members in order to test alternative

ideas of development. The contrasting views of different interest groups (residents, businesses, heritage experts, etc.) could be tested, and the consequences of each resulting scenario could be quantitatively and qualitatively assessed. In doing so, HLM could take advantage of the recent experiences in 'participatory modelling', developed in other research areas such as climate change, nature conservation, ecosystems and water management (Sterling *et al.* 2019). Participatory HLM could contribute to achieving some of the most elusive goals laid out in the European Landscape Convention: to involve stakeholders effectively in the planning and management of landscape and heritage (Moore *et al.* 2020; Turner *et al.* 2021).

HLM could also contribute to improving the methodological framework of computer modelling in social science and ecology. Simulating landscape character change raises different issues compared to simulating land-use change, since the driving forces that trigger transformation are often more complex and the processes that control spatial patterning are frequently obscure. New technical solutions and new theoretical frameworks need to be tested to produce modelling protocols that can overcome such issues. Being at the interface between social sciences and ecology, HLM protocols could influence computational approaches in both these fields (Elsawah *et al.* 2020), and hopefully foster a more solid integration and dialogue between the two.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was supported by the Katip Çelebi-Newton Fund (Research Councils UK (RCUK No. AH/P005829/1) and the Scientific and Technological Research Council of Turkey (TÜBİTAK No. 116K829) Research Partnership).

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Francesco Carrer is a Newcastle University Academic Track research fellow. A prehistoric archaeologist by training, he specialised in the study of archaeological and historical landscapes, with particular attention to mountain and pastoral landscapes. His expertise includes the use and development of GIS and statistical tools for the analysis of spatial patterns and the simulation of

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Mark Jackson is Senior Lecturer in Archaeology and Head of Archaeology at Newcastle University, UK. His main research interests are the archaeology of Roman, Byzantine and early Islamic periods in the Eastern Mediterranean. He has extensive field experience from projects in Turkey, Cyprus and Greece. He was Co-director for the Byzantine on the Kilise Tepe Archaeological Project and has worked on excavated material from elsewhere in Turkey including at Alahan and Çatalhöyük and on several surveys. In recent years has been leading a team working on the artefacts from the Apalirou Environs Project, Naxos. He also has a research interest in the history of archaeology and early archaeologists – especially Gertrude Bell – and is responsible for 8000 photographs in the Gertrude Bell Archive which was recently made a UNESCO International Memory of the World.

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Sam Turner's research is focussed on historic landscapes and medieval archaeology. He has worked at Newcastle University (UK) since 2004, where he is now Professor of Archaeology and Director of the McCord Centre for Landscape. He studied for a PhD at the University of York and worked previously at Devon County Council Historic Environment Service. His current work includes projects on historic landscapes in various parts of Britain, Europe and the Mediterranean. He is Co-Editor of *Landscapes*.

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