CHAPTER 1

Introduction – Understanding and managing landscape change through multiple lenses: The case for integrative research in an era of global change

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> *The twenty-first century is when everything changes. And we must be ready.*
>
> *(BBC 2006)*

The world is changing. It has always been changing, as internal geophysical processes drive the tectonic systems that slowly rearrange the distributions of land masses and oceans and external influences such as orbital eccentricities alter the Earth's climate. Over hundreds of millions of years, the physical and ecological environments at any given location on land have been shaped and reshaped by natural then, from the late Pleistocene onwards, increasingly by human processes – so much so that some argue for a new geological epoch (the Anthropocene) in recognition of this (see Steffen et al. 2011; Brown et al. 2013). Our recognition of different kinds of impacts and implications of landscape changes has developed in parallel with the increasing rates of industrialisation of the last 250 years (Hooke 2000; Wilkinson 2005; Montgomery 2007). Humans are highly inventive in providing technological 'solutions' to feeding, watering and providing energy for ever-increasing populations, but this inventiveness does not always produce resilient or sustainable solutions. Indeed, it is often only when we are highly dependent upon these technologies that we begin to understand their negative effects on the environment that also sustains us. This is a reflection of both scientific advancement throughout the period and the increasing impacts on landscapes of the expanding industrial activities, including the industrialisation of agriculture, water and energy provision. However, although we know some of the impacts of these technologies on natural landscapes and the 'ecosystem services' that they provide, many aspects of the natural functioning of these landscapes remain uncertain.

The continually increasing population of the Earth has inevitably led to the expansion of anthropic modification of landscapes into increasingly marginal (in terms of primary productivity) or unstable (in terms of ecology and/or geomorphology) lands. The associated risks have driven much of the agricultural and geomorphological research that has provided the

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basis for the management of landscapes undergoing such changes. However, towards the late 20th century, there developed a greater awareness of the potential for long-term catastrophic losses of productive agricultural lands as a consequence of inadequate or inappropriate management (e.g. Montgomery 2007), usually stemming from inadequate relevant scientific knowledge – or the lack of communication, or application, of that knowledge in policy formulation. The early years of the 21st century have also focused attention on the potentially increasing risks of natural hazards arising from regional manifestations of anthropic, global climate change. Extreme climate events lead to floods and landslides and wind storms, all of which cause losses of life, property and livelihood, but they may also lead to more chronic adverse impacts on societies through losses of land productivity – and these effects may be exacerbated by inappropriate land management strategies and agricultural practices.

John B. Thornes recognised the importance of good basic and applied geomorphological knowledge for the sound management of landscape change relatively early. Many of his ideas were developed from his early research experiences in central Spain in the mid-1960s, although his work on the particular problems of semi-arid environments did not begin until 1972 (e.g. Thornes 1975). Fundamental to his work was the development of modelling approaches for understanding geomorphological processes and systems in parallel with the implementation of intensive field data collection methodologies to support the parameterisation of the models. Perhaps crucially, he identified the need to measure not only 'descriptive' parameters such as morphology or particle size – typical of early quantitative geomorphology – but also landscape properties and processes that would allow quantification of the key geomorphological issues of spatial *and temporal* scale and variability. As such, he was a key player in the adoption of both monitoring and modelling approaches in geomorphological research and a leader in the explicit integration of these approaches and in the application of the findings to management policy and practice. For John, geomorphology included climate, hydrology and vegetation and their interactions with geomorphological processes and thus forms and their dynamics. As well as the management of modern processes, this interaction between process and form also informed John's understanding of past environments, particularly in his work on palaeohydrology and geoarchaeology.

Monitoring, modelling and management

Monitoring in environmental science is the process of keeping track, over time, of how one or more material properties or system states behave, based on repeated observations and measurements. It underpins the empirical understanding of environmental processes by observation of their consequences. For example, investigation of micro-scale controls on the process of soil matrix throughflow could require monitoring of water temperature (material property), soil water content and instantaneous flow velocity (static and dynamic system states, respectively). In geomorphology, many material properties are effectively constant at the timescale of a research project, but for other variables, the monitoring data required and hence the method by which they are obtained depend on the spatial and temporal scales of the problem being investigated. Technological advances over the last 30–40 years have increasingly expanded the range of what can be measured (i.e. parameter/variable type and scale) and at what frequency, although in some cases there remain constraints. For example, satellites cannot yet provide both very high temporal frequency and very high spatial resolution data – although most applications of this approach such as monitoring land-use change do not require high frequencies of repeated observations, and rapid developments in UAV techniques are addressing some of these limitations at local scales. Most field monitoring takes place at points, and the cost of equipment and labour to maintain field monitoring 'stations' means that there are often relatively few of these, so that significant interpolation is required for landscape-scale analysis. However, it must be remembered that remotely sensed observations are proxies of the properties or system states of interest and must be grounded in field measurement.

Modelling is the process of representing or displaying something that cannot otherwise be experienced, through abstraction of reality and representation in the form of a conceptual, mathematical or physical model. John Thornes was one of the pioneers of mathematical models in geomorphology, which are increasingly used as representations of geomorphic systems. They are usually used as a way of evaluating conceptual models of components of a system such as a specific process or a topographic subsystem representing a set of processes; furthermore, today's office PCs can typically carry out hundreds of simulations using highly sophisticated models and produce the results before the morning coffee break. However, as with any investigation, the type and formulation of the model necessarily depends on the purpose of the research and, critically, on the quality and quantity of data that may be available to set up the model and evaluate its outputs (Mulligan and Wainwright 2004). John always understood that the geomorphological processes of greatest interest to him existed within a complex context. Over his career, through his own research and that which he supervised, collaborated with or helped to fund, he tried to ensure that as much of the relevant contextual complexity as was useful, was included. In his modelling of erosion, he started by defining and representing the process itself (Embleton and Thornes 1979). Subsequently, he introduced interactions with terrain, climate and geology (Thornes and Alcántara-Ayala 1998), then vegetation (Thornes 1990) and finally animals (Thornes 2007). All of this was done with a clear focus on the socio-economic context and the policy outcomes (Brandt and Thornes 1996; Geeson et al. 2003) and an understanding of the role of time (Thornes and Brunsden 1977) and of history (Wainwright and Thornes 2003).

The degradation of agricultural lands in the Mediterranean region has been investigated at all spatial scales, from small experimental plots on hillslopes to remote sensing of the entire region. One of the major challenges has been to integrate not only the monitoring data with the modelling of erosion processes and changing state of the landscape system but also the findings from different scales of investigation into regional-scale, operational management tools. John Thornes was quick to embrace the possibilities presented by GIS technology (particularly digital elevation models) and satellite remote sensing and the integration of such techniques with smaller scale field studies and process or system models. Indeed, combining field and remote sensing-based monitoring with modelling was one of John's key foci during the latter part of his career, particularly in the European Mediterranean. He then led the development of the conceptual framework that ultimately led to the GIS-based and web-based, management-focused tools that came later. These will undoubtedly continue to be refined, not least to accommodate the threats to sustainability deriving from new technologies and/or revealed by ongoing monitoring programmes.

Management is used here in its broadest sense to refer to all levels of application of research findings by different agents, ranging from individual farmers and local communities through to regional managers and national/international policymakers such as the US federal government or the European parliament. We also use it to include all types of management, from details of how an individual field with particular soil types and rainfall patterns should be ploughed and then planted up to multi-decadal plans for new water resource infrastructure. The outputs of several of the desertification research projects initiated by John Thornes and outlined in this book provided outputs that are designed to be applied at all scales of application including EU-scale funding decisions. Application of research so as to have tangible effects on individual farmers, governmental policies and/or any other level of governance or commercial activity would constitute what is now generically referred to as 'impact' in the UK research context. 'Impact' is now a critical element of any research funding proposal from public funds (e.g. the UK Research Councils) and research quality assessments that determine how much money is given to each individual university to support research. It is arguably the case that measurable or evidenced research 'impact' is more likely to arise from more integrated and synthetic research projects that incorporate and integrate a greater number and type of research 'elements', that is, methodologies/techniques, disciplines, commercial or other organisational partners (providing end-user perspectives).

The strength of geomorphology as an academic discipline lies in its fundamental importance to so many aspects of society, thus being well placed to succeed in the increasingly selective and output-driven research funding environment in the United Kingdom and many other countries. Multinational engineering companies have built up substantial and interdisciplinary geomorphology teams in recent years, and insurance companies as well as national governments continually seek improved evidence of probabilities of damaging natural hazards occurring requiring hydrological, ecological, geomorphological and socio-economic research. The latter example provides a practical application of geomorphological research to the issue of tectonic hazards, such as interpretations of new evidence for frequency, nature, scale and thus possible impacts of earthquakes, volcanic eruptions and tsunami in particular locations. It is perhaps unfortunate that insurers probably tend to use the higher end of any range of probabilities of occurrence (i.e. more likely), whereas policymakers may be keen to emphasise the lower end in order to defer having to commit to public spending on mitigation measures! However, as more different types of evidence are obtained and integrated, often from different disciplines and using different approaches and techniques, so the uncertainties are reduced, weights of evidence increased and overall credibility in any headline message is increased among the potential end users. John Thornes showed how geomorphology could integrate and structure information from other disciplinary areas and recognised the need for understanding complex systems in a non-reductionist way (e.g. Thornes 1985; Wainwright 2009). His collaboration with Antonio Gilman demonstrated the value of geomorphology to archaeology (Gilman and Thornes 1985), and there are many other examples of interdisciplinary research and commercial applications in ecology (Nortcliff and Thornes 1988), hydrology (Francis and Thornes 1990; Dykes and Thornes 2000), climate (Thornes and Alcántara-Ayala 1998) and society (Trimble and Thornes 1990; Thornes 2005).

Aims, purpose and structure of this book

The aim of this book is to demonstrate the lasting significance of the integrated monitoring and modelling philosophy of geomorphological research pioneered by John Thornes, by reporting recent and ongoing research and applied work that utilise this approach. This collection of work includes a wide range of types of research and applied studies undertaken using this integrated approach and, as such, serves to demonstrate the value and effectiveness of adopting such an investigative framework. The authors of all of these works are academics and practitioners who were either taught by John Thornes as postgraduate (and in one case undergraduate) students or who worked with him on one or more research projects, and their present colleagues and research partners. John's inspirational teaching and leadership is reflected in the enthusiasm with which the contributors agreed to write for this book, which should also serve as a lasting tribute to his academic career as a leading geomorphologist. The book is structured in two parts. The first is made up of studies inspired and informed by the philosophy outlined earlier, while the second reflects more directly on John's own contributions to the discipline.

Part 1 of the book is made up of chapters that vary in emphasis from data collection (monitoring) at one extreme to the application of models to policy development at the other. The first six chapters cover this range and, as such, broadly parallel the changing focus of John Thornes' research in Spain and, later, most of southern Europe. Romero Díaz and Ruíz Sinoga (Chapter 2) examine the measurement of soil erosion in Spain, starting with methods initiated by John Thornes. Through their examination of scale effects and other factors relating to the measurement and monitoring techniques used, they highlight the potential difficulties of obtaining data that can be used reliably to quantify soil loss and, thus, set up and indeed validate models of soil erosion for varying soil, slope and vegetation conditions in particular. Cerdà et al. (Chapter 3) report findings from a later stage of experimental fieldwork that examined the influence of shrubs on the hydrological and erosional conditions of Spanish hillslopes, demonstrating an effect identified and argued by John Thornes long before relevant monitoring was undertaken to provide data that could enable the effect to be modelled. Hooke and Mant (Chapter 4) further highlight the difficulties of parameterising models in their presentation of combined flood and vegetation change data for ephemeral channels in Spain. In this study, the integration of two themes – channel morphology and vegetation dynamics – appears to have greatly increased the apparent level of complexity inherent in the connectivity between these landscape components.

More emphasis on the value of modelling is provided by Wainwright (Chapter 5) who discusses conceptual frameworks for attempting to analyse the nature of the complexities of past land use and associated geomorphological change in the Mediterranean region. The key element here is the development of a non-linear modelling framework that integrates not only vegetation and erosion processes but also the evidence of patterns of human settlement, effects of agricultural practices and, often, later abandonment. In Chapter 6, Brandt and Geeson explain how the scientific findings of the desertification research relating to contemporary environmental and socio-economic pressures, that is, incorporating anthropogenic factors integrated with knowledge of the range of geomorphological and ecological processes, were made available to end users. This chapter demonstrates the importance of engaging with all types of end users from practitioners to managers, as well as other scientists, while undertaking the research and designing the outcomes of the research to be as user-friendly as possible across the board. Mulligan (Chapter 7) takes many of these ideas a further step forward by presenting the historical timeline of a web-based modelling framework that simulates the effects of particular policy decisions relating to management of sensitive and highly variable landscapes in the Mediterranean and beyond. With provenance in the early monitoring and modelling of Mediterranean desertification under John's supervision, this framework is now a sophisticated spatial policy support system in wide use at various levels of decision-making around the world.

Subsequent chapters present hydrological, geomorphological and environmental management studies undertaken in a variety of global contexts, reflecting the very wide range of John's interests and activities beyond his core focus on the Mediterranean region. His particular concern for water resources and water management in semi-arid environments and elsewhere, as well as natural hydrological processes and systems, provide a common theme for Chapters 8–10. In Chapter 8, Francis and Lowe examine the studies behind the preparation of a strategic integrated regional plan for sustainable development in the Rift Valley Lakes Basin of Ethiopia and in particular the assessment of environmental impacts of any natural resource exploitation. There is an emphasis on water resources throughout a programme of work that necessarily and explicitly followed an 'integrated philosophy'. Watts, on the other hand (Chapter 9), focuses on the modelling of water resource planning for the United Kingdom, highlighting both the modelling and management issues driving the approaches used and the application of the research findings. Marsik et al. (Chapter 10), concerned with changing river flows potentially reducing water supplies in Costa Rica, present research findings that attempt to explain the changing discharges in terms of catchment-wide land-use and/or climate change. They highlight the importance of combining multiple approaches in order to adequately investigate the problem.

The next three chapters focus on different types of geomorphological research. Afana and del Barrio (Chapter 11) present an adaptive model of channel network development that has been designed to facilitate the future integration of additional catchment properties to enhance the depiction of landscape change. The DEM framework provides the basis for parameterisation, in contrast to the work reported by Dewez and Stewart (Chapter 12) in which the DEM *is* the landform model. Here, the results of a semi-automated analytical procedure are interpreted with respect to the local tectonic context to explain the formation of a sequence of coastal terraces. In Chapter 13, Dykes and Alcántara-Ayala use slope stability models as part of an investigation of the role of land-use changes in the incidence of damaging landslides in Mexico. The context of land-use monitoring is reviewed, and the difficulties of utilising such land-use data in stability and hazard analyses are demonstrated.

Part 2 comprises a short collection of overviews of John's contribution to geomorphological research and the application of that research to real-world problems, rounded off with a short biography, written by some of his major contemporaries, colleagues and friends. The purpose of these chapters is to provide a scientific and historical context for (i) the wide range of related contemporary research in semi-arid regions and particularly in Mediterranean countries and (ii) the interests and scientific approaches utilised by students and colleagues of John that were strongly shaped by his influence.

We believe that John would have approved of the continuing sense of scientific rigour and exploration embodied in the studies presented here. That his influence continues on to present and future generations is a fundamental reflection of the significant advances that he made both directly in the discipline of geomorphology and more broadly in developing approaches to sustainable management of the environment.

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