Chapter 15
Land Degradation in Drylands: Reëvaluating Pattern-Process Interrelationships and the Role of Ecogeomorphology

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Abstract In this book we have argued that improved understanding of land degradation in drylands needs a problem-centred multidisciplinary approach. Specifically, we have argued for an ecogeomorphic approach. In this concluding chapter we review successes and shortcomings of this approach, identify key challenges that need to be overcome, and present the conceptual and methodological advances that need to be made to overcome these challenges. There has been a wealth of research investigating patterns and processes separately at small spatial scales, and, some advances in linking ecology and geomorphology have been made. However, there remains little in the way of true integration across the disciplines that deal with both ecogeomorphic patterns and processes. To overcome this weakness,

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it is imperative that the lessons of ecology are learned – to value truly coupled eco-hydro-geomorphic studies, in which biogeochemistry, plants, geomorphology, soils and hydrology are all well represented and experimentally manipulated – and that the lessons of geomorphology and hydrology are learned: to value observational studies in which ecological measurements are coupled with hydrological and geomorphological measurements, and the role of exogenous forces is explicitly recognized. No one approach will be applicable to understanding land degradation in drylands. Unique settings, both biophysical and cultural, mean that the solutions to land degradation differ from place to place. Furthermore, evolutionary changes in drylands – degraded or otherwise – mean that methodological approaches employed to study the system may need to be fluid. We conclude the chapter by identifying five key challenges for land-degradation studies in drylands. First, a common language needs to be developed. Secondly, the problem of scale and scale interactions needs to be overcome. Thirdly, the lessons of complexity science need to be accepted and acted upon. Fourthly, the understanding of the interactions of ecogeomorphic processes and people needs to be improved. Fifthly, management strategies for combatting land degradation in drylands need to be developed taking account of scientific advances, but not waiting for an "ultimate solution" that will never arrive.

15.1   Introduction

Patterns and processes are mutually causal. Therefore, in this book, which is the primary outcome of a workshop funded by the European Science Foundation (ESF), we have attempted to take a centripetal, ecogeomorphic approach to improve understanding of pattern-process linkages in drylands (Fig. 1.3). In the preceding chapters, we have explored how an ecogeomorphic perspective – the integration of ecology and geomorphology – can improve our understanding of patterns and processes of land degradation in drylands. Multiple examples have been presented which demonstrate that the emergence of patterns develops from a complex interplay of processes and associated horizontal and vertical fluxes of energy and materials over multiple spatial and temporal scales. These processes and fluxes have, for the most part, been considered in isolation of each other, in both monitoring- and modelling-based studies. However, interactions between these fluxes, feedbacks linking different components of the ecogeomorphic system, and the existence of self-organizing states where resource patterns develop as an optimized response to climatic and landscape conditions intrinsic to dryland systems require interdisciplinary research approaches. Interdisciplinary research is also vital if the rôle of human activity in the dynamics of these systems is to be appropriately investigated and understood. It has become increasingly evident throughout the preceding chapters that the development of integrated ecogeomorphic studies need to encapsulate both field-based experimentation and model development, which together will enable the effects of drivers of land degradation and emergent

phenomena to be disentangled. Consequently, this integrated approach will permit an understanding of the controls on the dynamics of land degradation which is a prerequisite for its successful management.

In this concluding chapter we review the successes and shortcomings of current ecogeomorphic approaches to land degradation in drylands, and set this approach into a broader scientific context. From this review, we identify key challenges that need to be overcome in order to advance research within an ecogeomorphic perspective and identify conceptual and methodological advances that should be made to overcome these key challenges.

15.2   Land Degradation in Drylands: State of the Art

Land-degradation studies have made great headway in recognizing the importance of interactions and feedbacks between ecological and geomorphological processes on shaping patterns and processes in drylands (e.g. Okin et al. 2006; Peters and Havstad 2006; Stewart et al., in press; Turnbull et al. 2008; Wainwright et al. 2002). However, there remains a tendency for land-degradation studies in drylands to focus on isolated components of the system or at best one or two ecogeomorphic feedbacks (following the centrifugal approach, as was depicted in Fig. 1.3). Furthermore, studies are typically undertaken at one scale of inquiry which is a major limitation since ecogeomorphic feedbacks tend to span multiple spatial and temporal scales.

Through exploring ecological and geomorphic research during the ESF workshop and through the compilation of the preceding chapters of this book, we have been able to evaluate the commonalities and disparities in ecological and geomorphic research approaches, areas where connections have been made, and areas where deficiencies remain. Here, we outline some of the key successes and shortcomings of ecogeomorphic research in drylands that have been identified in the preceding chapters and outline a research agenda in order that future research may overcome these shortfalls.

The preceding chapters of this book have demonstrated that there has been a wealth of research investigating patterns and processes separately at small spatial scales (Chap. 4), and we now have a reasonably comprehensive understanding of both ecological and geomorphic processes at these small scales. An increasing array of tools has been developed to facilitate high-resolution data collection which has been beneficial in improving the parameterization and testing of ecological and geomorphic models (Chap. 8). These data have also facilitated the study of long-range processes (Chap. 5), but there has been a general failure to integrate research on the short- and long-range scales. In addition, major advances in technology and freedom of information over the recent decades have enabled the observation and evaluation of pattern in drylands over significant parts of the Earth's surface. Furthermore, major accomplishments have been made in modelling isolated components of the ecogeomorphic system, which to varying extents, work

reasonably well for simulating processes at specific spatial and temporal scales and specific environmental conditions (Chap. 7). These model developments have resulted from increases in process understanding derived from empirical studies, and in some cases, have highlighted gaps in empirically based process understanding, thus providing new directions for empirical research. These system-component models have provided a platform upon which to identify the challenges of developing integrated ecogeomorphic modelling approaches, not least those relating to the effective incorporation of uncertainty in measurement and model structure (Chap. 10). Finally, this book has provided the first interdisciplinary platform for ecogeomorphic studies in drylands, and has provided clarification of terms that are used across disciplines, but often with different meaning. The case studies show how differently disciplines deal with the analysis of vegetation-terrain interactions. For example, Barbier et al. (Chap. 13) studied the types of different vegetation patterns derived from remote sensing imagery or through numerical approaches in the form of spatial symmetry-breaking models using advanced Fourier spectral analysis and related gap proportion and pattern wavelength of vegetation patterns to regional topographic or annual climatic gradients to understand potential trigger mechanisms of spatial patterning. No process mechanisms regarding plant functioning, matter or energy fluxes were included in their approach. Similarly, Dunkerley (Chap. 12) employed a cellular automaton (CA) model on an annual time step to model explicitly the changes of vegetation establishment and growth as a function of water availability using simple rule-based algorithms. In contrast, in Chap. 11 Turnbull et al. discussed the application of a process-based ecogeomorphic model to the understanding of vegetation and surface changes in an explicit way. The model demonstrates that more process and spatial detail are often required to address the limitations imposed by equifinality.

15.3 Shortcomings of the State of the Art and How to Overcome Them: A Research Agenda

In land-degradation studies, the state of the art is a compendium of more-or-less independent pieces of research, lacking an overarching conceptual framework. Although some advances in linking ecology and geomorphology have been made through the (International) Long-Term Ecological Research ([I]LTER) programmes and through US Department of Agriculture-Agricultural Research Service experimental catchments, there remains little in the way of true integration across the disciplines that deal with both ecogeomorphic patterns and processes (but cf. Stewart et al., in press: see Chap. 11). The different research programmes that have evolved within ecology and geomorphology and contrasting research agendas have led to the development of somewhat different research approaches that now challenge the integration of these disciplines because of a lack of compatibility and acceptance of different research approaches across the disciplines. For example,

many ecologists have a preference for replicated multi-factorial experiments which are not feasible in large-scale (eco)geomorphic studies that, as a result, tend to be unreplicated, not least because of the importance of the uniqueness of place as discussed in Chap. 5. There has to be a mutual acceptance and understanding of different research approaches and willingness to compromise in order to be able to carry out coupled ecogeomorphic studies. The challenge therefore is to determine how an ecogeomorphic approach can combine these different methods and research strategies to answer research questions, test hypotheses, and enable theoretical advances to be made in degradation studies in drylands. For these advances to be made, it is imperative that the lessons of ecology are learned – to value truly coupled eco-hydro-geomorphic studies, in which biogeochemistry, plants, geomorphology, soils and hydrology are all well represented and experimentally manipulated – and that the lessons of geomorphology and hydrology are learned: to value observational studies in which ecological measurements are coupled with hydrological and geomorphological measurements, and the role of exogenous forces is explicitly recognized (Turnbull et al. 2012). The optimal research strategy for land-degradation studies in drylands will apply these research approaches in tandem – replicated (where possible), experimental manipulations, combined with both short- and long-term observations and modelling-based approaches. Clearly though, to address land-degradation problems in drylands, a multitude of these methodological approaches need to be employed, with triangulation between observation, experimentation and modelling. Similarly, the different approaches to the "top-down" or "bottom-up" specification of scientific problems (see discussion in Chap. 2) need to be accommodated, and different styles of research into similar questions not dismissed out of hand.

However, any research strategy for land degradation in drylands has to recognize that no one approach will be applicable to all drylands. Unique settings, both biophysical and cultural, mean that not only may the solutions to land degradation differ from place to place, but so, too, may the research approaches needed to identify those solutions. Different styles and approaches will be particularly important for breaking the 'hierarchical relationship' in understanding physical and social causes of land degradation (Chap. 2), to ensure we move beyond understanding human and physical components of dryland systems as simply providing the initial and boundary conditions for one another. Such work may bring new uncertainties (Chap. 10) and seem risky for individual researchers, but it is necessary to move beyond narrow scientific disciplinary specialization. For example, degrading drylands are ever evolving and because of the contingency this evolution produces, replication may be impossible. The lessons of complexity science need to be learned to bring together the different components of the ecogeomorphic dryland system in a unified and appropriate way. Furthermore, place-based, comparative, and long-term research is needed to understand coupled social-ecological systems (Carpenter et al. 2009), in order to help drive social-ecogeomorphic research and the management of dryland systems.

While several modelling studies have investigated hydrological, geomorpho-logical and ecological patterns simultaneously (e.g. Wainwright et al. 2002;

Mueller et al. 2007), some taking a complexity-based perspective (Stewart et al., in press; Chap. 11), there have been no field studies that have convincingly looked at hydrological, geomorphological and ecological processes simultaneously. Furthermore, there are a limited number of studies within ecology and geomorphology that integrate data sets from the plot scale up to regional scales. In general, long-range processes have not been so well studied as short-range processes, which is largely because of methodological limitations. In general, there has been a focus in geomorphology on the study of horizontal fluxes of materials and energy, while in ecology there has been more of a tendency to focus on vertical fluxes of materials and energy (but see Turner 1989). A pattern-based approach leads to the need to integrate across scales, because once pattern formation is viewed as the outcome of linking of short- and long-range processes (see Chaps. 2 and 3) existing scale-bound approaches are found lacking. Furthermore, the variables of interest within ecology and geomorphology are generally very different, with only soil moisture and nutrients being commonly studied within both disciplines. In fact, no strictly true ecogeomorphic case studies exist that explicitly consider the critical ecogeomorphic components outlined in Fig. 1.3. Even the studies that were presented in Chaps. 11, 12, 13 and 14 are still limited in the extent of their true ecogeomorphic coupling.

Monitoring cross-scale interactions and feedbacks using experimental approaches is inherently challenging, as current experimental approaches favour monitoring processes at one spatial scale. The continued development and refinement of ecogeomorphic modelling approaches is likely to be the most valuable research tool available for investigating cross-scale interactions and feedbacks in land-degradation studies. While the application of discipline-specific models can be successful at limited spatial and temporal scales, these models tend not to include system feedbacks between multiple elements of the ecogeomorphic systems (e.g. Baas and Nield 2010; Tietjen et al. 2010, see Chap. 7), and hence do not allow an integrated functioning of the system and emergent phenomena. Modelling becomes more challenging at larger spatial scales due to computational limitations, limited amounts of available ecological and geomorphological data that span the same spatial and temporal scales and a more limited understanding of process interactions.

Continued refinements of fine-scale deterministic models are to be encouraged, but the obstacles in translating these results to different scales need to be explored more explicitly (Marston 2010). During the ESF workshop, several key areas were highlighted that are necessary to underpin developments for the successful implementation of ecogeomorphic modelling in land-degradation studies. It was established that we need to continue advancing process understanding within ecogeomorphology, to understand feedbacks and interactions between biotic and abiotic processes and their controlling factors, and to understand linkages between hierarchical levels of organization. Incorporating mechanistic linkages between different hierarchical levels must be at the forefront of ecogeomorphic model development, where hierarchical modelling approaches are used. We need to establish the minimum parameterization requirements which can reasonably be expected to

be sufficient for ecogeomorphic modelling, because inclusion of too much detail in both parameterization and process representation may increase sensitivity and error propagation (Deutschmann et al. 1997; see also Chap. 10).

Linking data from experimental approaches with models is a critical research frontier. However, both the suitability of experimental data for the desired approaches to modelling, and the feasible approaches to modelling given the practical constraints on experimental data collection need to be evaluated further. A key aspect of such investigation is the need to incorporate uncertainty analysis, especially if model-parameterization requirements increase since model output cannot be truly evaluated or compared to observations unless uncertainty in both is acknowledged and incorporated into the evaluation and comparison (see Chap. 10).

A common goal of ecologists and geomorphologists working from monodisciplinary perspectives, pertaining to issues of land degradation in drylands, is to understand the mechanisms behind pattern-process relationships. In developing this understanding, a fundamental problem is the clear separation of the roles of drivers and emergent properties; be that in models or empirical understanding. That separation is confounded by the fact that drivers and emergent properties are scale-dependent. What is a driver at one scale may be an emergent property at another, and *vice versa*. For example, islands of fertility are emergent landscape *features* of resource distribution at the plant-interspace scale (Schlesinger et al. 1990), but may be *drivers* of redistribution of resources by runoff at the hillslope scale (Parsons et al. 2004; Brazier et al. 2007). Furthermore, drivers of degradation will vary across different dryland regions. For example in Mediterranean Europe land use (i.e. agriculture and grazing) is likely to be more important than climatic drivers (e.g. Kosmas et al. 1997; Papanastasis et al. 2002; Wainwright and Thornes 2004, Chap. 14), whereas in the US Southwest, grazing alone seems more important, at least in some locations (Chap. 11). The role of human drivers of land degradation has been under-researched within the framework of ecogeomorphology (Wainwright and Millington 2010). However, humans are a fundamental part of almost all ecogeomorphic systems and need to be integrated with our ecogeomorphic understanding. In this sense, output from ecogeomorphic modelling needs to be carefully tailored so that it can be used effectively in practical applications. For example, model output needs to be at spatial scales relevant for land management. In achieving this goal, selection of the scales and relevant components of analysis need to be cognizant of the perils of observer dependence.

Any proposed approach to advancing a solution to the problem needs to be mindful of the limited resources for solving any human-environmental problem. Greater use of existing data sets (particularly long-term data sets) and techniques of data mining coupled with the use of proxy measurements (for example remote-sensing data) can lead to more efficient strategies for new data collection and the optimization of their use. A particular problem to be addressed is that of large-scale processes, both in space and through time. It is unrealistic to expect this problem to be addressed through direct experimentation, yet solved it must be.

At the end of the ESF Workshop, the participants were asked to identify the three key challenges in the study of land degradation in drylands. The results of this

exercise showed there is still much to be done in terms of identifying a common research agenda: the key challenges were disappointingly numerous and there was no strong convergence of thinking apparent between the disciplines, but then again a two-day workshop might have been too short to achieve that. The following section attempts to embrace the different perspectives by setting up five key challenges for land-degradation research.

15.4 Key Challenges for Land-Degradation Studies in Drylands

In Fig. 1.3, we proposed that for a true ecogeomorphological perspective, researchers should look outward from the problem of land degradation towards contributory disciplines rather than outward from their disciplines towards problems to be addressed. In this final section, we wish to argue that an ecogeomorphological perspective, interdisciplinary as it may be, is still too narrow a perspective from which to address the problem of land degradation in drylands. Figure 15.1 places the ecogeomorphological perspective in a broader scientific perspective. From this broader perspective, and within the context of the outcome of the workshop, the key challenges for land-degradation studies in drylands have been identified.

These challenges are both conceptual and practical. We have identified five key challenges that need to be overcome for truly interdisciplinary ecogeomorphic approaches to yield a common understanding of the problem and potential solutions across the disciplines.
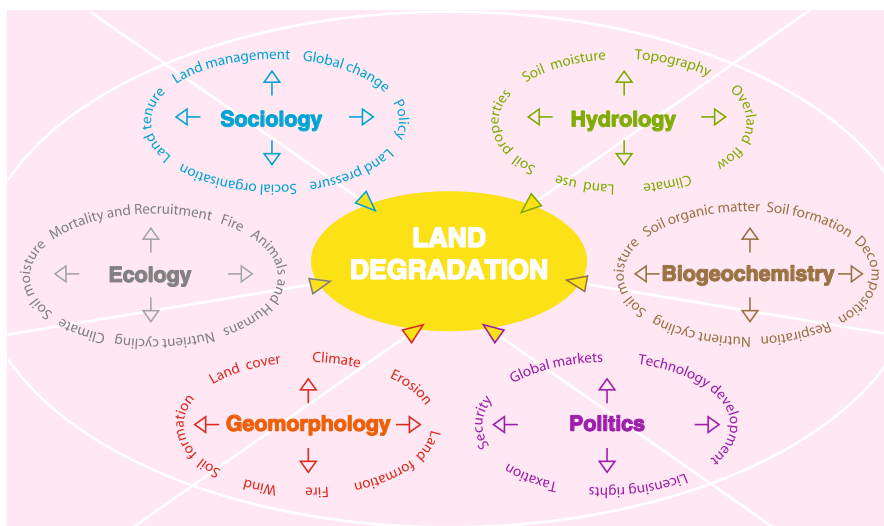

Fig. 15.1 Role of ecogeomorphology in a wider conceptualizing of land degradation in drylands

15.4.1 Develop a Common Language

Ultimately, the successful integration of ecological and geomorphological knowledge and principles within ecogeomorphology will depend on the level of theoretical compatibility as much as practical challenges and a common language, scalability of investigations, and data collection (Urban and Daniels 2006). The functioning of interdisciplinary work has been studied intensively (Balsiger 2004). Evans and Marvin (2004) noted that previous attempts at interdisciplinary research often resulted in multidisciplinary research being undertaken from a range of different (discipline-bound) perspectives, rather than leading to approaches that are truly interdisciplinary. Several problems arise frequently from recognised differences between discipline-based experts including: fundamental differences in epistemologies, knowledge and methods, a range of 'attitudes' across disciplines, different ways of formulating research questions and differences in communication (both oral and written) (Bracken and Oughton 2006). However, perhaps the biggest problem of all is that of scientists communicating without noticing that they do not understand each other. Discussions may be well-developed before it becomes apparent that a particular word or terminology has a specific disciplinary interpretation not known to scientists from other disciplines.

In the course of the ESF workshop and the compilation of this book, recurrent terminologies were clarified (such as model, scale and emergence: see Chap. 3). While formal definitions of recurrent terminologies are useful, they fail to capture the breadth and dynamism of language and multiple meanings of key words in use thus potentially inhibit the construction of knowledge. Different disciplines, and even those taking different approaches to the study of the same discipline (such as modellers and experimentalists), may tend to have different starting points for thinking about a specific word, such as watershed or connectivity, or terms such as land use or self-organization, and those working within those disciplines have been trained to think in different ways. The difference between disciplines results in conceptual boundaries being drawn in different ways and at different spatial and temporal scales. Language boundaries can be transcended if articulation is employed as a means to deconstruct one's own disciplinary knowledge in conjunction with those of other disciplines in order to understand the building blocks of an expression and thereby reconstruct a common understanding or to produce a more complex definition of a term (Ramadier 2004; Bracken and Oughton 2006). The first step in developing a common language for research may therefore be the need for a new trading, or pidgin, language which develops terms with shared meaning (McConnell et al. 2011). In turn, this pidgin can provide the basis for a creole language with a more formal grammar capable of describing more sophisticated concepts and interactions. The articulation required to overcome the boundaries of language and knowledge can be achieved by a set of truly integrated research projects. Integrated projects must allocate time to the development of shared vocabularies and way of thinking by having longer start-up phases to promote

cohesion and to learn to value contributions from other disciplines: such projects require professional management to handle initial language and thought barriers (Bracken and Oughton 2006).

A common language and cross-disciplinary thinking has to be established by having all team members involved at some level in all aspects of the work, rather than just contributing to an output which it is hoped will be greater than the sum of its parts. Modellers teamed up with experimentalists, and geomorphologists teamed up with ecologists (and others identified in Fig. 15.1), should frequently test their assumptions and perceptions of setting up models, fieldwork, spatial and temporal data analysis, and so on. Even though this process is time-consuming, it enables exposure of disciplinary ignorance, methodological weaknesses and superiorities in a constructive way (Bracken and Oughton 2006). The need for developing a common language is not only true for scientists from ecology, geomorphology and other involved disciplines, but also for the communication between non-local and local scientists, inhabitants and stakeholders managing, working and living in degraded lands.

15.4.2 Transcend the Problem of Scale

It is well established that processes and patterns occurring across different scales – both spatially and temporally – affect each other (see for example Chap. 6). Although there are examples where cross-scale interactions have received attention (e.g. Peters et al. 2006; Okin et al. 2006), they are few and far between, and they have received little or no attention in ecogeomorphic, field-based, land-degradation studies.

The continued development and refinement of ecogeomorphic modelling approaches in tandem with integrated cross-scale field studies is likely to be the most valuable research tool available for investigating cross-scale interactions. Modelling of potential ecogeomorphic feedback mechanisms and self-organizational patterns will provide guidance in selecting highly variable (in space and time) and relatively fixed parameters that are critical in driving the feedback or pattern organization and which may therefore require more focussed or detailed field investigation (e.g. Grimm et al. 2005). An important component of modelling-based experimentation is to carry out sensitivity analyses to identify the most important parameters in controlling the processes being modelled (Mulligan and Wainwright 2013; Ratto et al. 2001). Modelling should thus also guide existing long-term monitoring schemes that should be enhanced and, although keeping some coherence in their principal elements, should be continuously developed in their aims and set-up. There should be a change of mind-set to envision the multi-decadal collection of data as a new standard in data mining to allow the analysis of temporal scaling in land-degradation studies. Although there are scientific movements towards adopting this

type of approach – such as the NEON (National Ecological Observatory Network) project which is perhaps a striking example of a new monitoring initiative that is aimed at collecting data over the long term for a range of parameters/variables (NEON 2012) – the real problem is the allocation of sufficient institutional vision, funds, staff and infrastructure to allow the work to take place.

Modelling and process studies need to address the specific temporal scales that are attached to the recurring or non-recurring triggers and drivers of land degradation. For example, a fire may trigger ecosystem change within hours and observation of fire impacts would focus on rather short times spans. However, fires may have multi-scale effects over a range of timescales such as persistent drought because of changes to the soil hydrology over several years that might alter soil-vegetation functioning in such a way that the system does not recover from the disturbance, up to evolutionary timescales where the form and/or function of species evolve to tolerate or adapt to repeated burning episodes. Landscapes characterized by a fire-adapted ecology will thereby have different geomorphic feedbacks from those where plants are not fire-adapted. These feedbacks will have differing spatial consequences because short- and long-range erosion processes (see Chaps. 4 and 5) will be triggered in different ways. Management decisions might cause an immediate change of land use, but changes to soil-vegetation interactions might only become apparent decades later such as with the effects of clear-cutting of *Eucalyptus* woodland in southwest Australia to provide land for irrigation agriculture, leading to severe salinization problems as a result of increased groundwater recharge (Cramer and Hobbs 2005; see also Chap. 14 on land abandonment in the Mediterranean region). Future management decisions may also be influenced by prior spatial patterns of land use and management which constrain ecological and geomorphic processes. Furthermore, temporal variability in drivers might vary over relatively short cycles such as the effects of El Niño on annual temperature and rainfall regimes (e.g. Dahm and Moore 1994; Wainwright 2005) or over much longer periods of centuries to millennia due to climate variations. A large array of records is readily available in some areas such as the US Southwest to assess temporal change of land degradation and their drivers, such as continuous coverage of multi-spectral remote sensing imageries, old air photography, erosion-pin analysis of hillslope evolution or regional records of livestock rates and subsidy measures. However, even where it is available, the degree to which this information is actually used to address questions of temporal scale is very limited. In many areas of the world, comparable data sources are not available. In the same way as pictures of the blue planet and subsequent large-scale development of remote sensing have allowed us to take on board large spatial scales and incorporate them in our studies, there is a need to develop techniques that allow us to conceptualize processes and their interactions over timescales longer than our perceptual basis – and certainly for longer than the artificial basis of the three-year research or PhD project (see also Klemeš 1997).

15.4.3   Take on Board the Lessons of Complexity Science

A related point is the current predominance of short-term, hypothesis-driven research. While such a deductive framework to research undoubtedly has its uses, one needs a more fluid approach to deal with research questions in land-degradation studies. Complexity science suggests that it is fundamental to address the roles of thresholds, path dependence, contingency and emergent behaviour in our understanding. In some cases, inductive approaches will be required to evaluate the effects of contingency and path dependence; in others "play" with a range of "toy" models may be the best way to interpret emergent behaviour such as pattern formation. Comparison of the behaviour of toy and process-based models will enable us to determine the necessary conditions for the formation of patterns in specific environments. Iterations between these two modelling approaches and the collection of field data at appropriate spatio-temporal scales are the only way to improve our understanding of process and system evolution. There should no longer be a barrier between nomothetic and idiographic approaches when solving complex problems like land degradation. Furthermore, given the need to incorporate thresholds, contingency and path dependence into our topics of investigation, it is fundamental that we design a research approach that is serendipitous. Major advances are rarely made when the scientific endeavour is locked into a phase of static mundanity (e.g. Eco 1998).

The more fluid approach to research is to advance logic that allows us to include uncertainty and allows us to include belief. Uncertainty (Chap. 10) enters our research process at every step along the way – whether we are prepared to admit it or not. Techniques are available to evaluate uncertainty of measurements and the propagation of error within a model, but the means of evaluating epistemic uncertainty, when the model structure itself is in error are much less clear, not least because the problem of equifinality means that simply comparing model results against measurements is no basis of providing an unequivocal result (see discussion in Oreskes et al. 1994; Mulligan and Wainwright 2013). To address the issue of epistemic uncertainty, we also need to consider the extent to which our belief in the behaviour of a particular system is moulded – notwithstanding the homogenization of a rigorous "scientific" training – by our experiences and also our usually insular disciplinary backgrounds (see discussion above and in Chap. 1). Unique settings, both biophysical and cultural, mean that not only may the solutions to land degradation differ from place to place, but so, too, may the research approaches needed to identify those solutions. Accepting this uniqueness and how it moulds our beliefs may also help in transcending the scale problem.

More flexible ways of looking at problems are also vital. For example, qualitative data are not only fundamental for evaluating the human interactions with land degradation (see Sect. 15.4.4), but also they can provide invaluable insights either into system behaviour (addressing issues of epistemic uncertainty) or data sources where information would otherwise be unavailable (see Chap. 10). We should therefore not be shy about using any source of information useful for solving the

problems of land degradation, for the benefit of the billions who depend on drylands for subsistence. If there are things out there that would be beneficial to your studies, make use of them. For example, old photographs can be used to study land-use change in a qualitative way in order to get information on long-term change (e.g. Hastings and Turner 1965; Nyssen et al. 2009), or diaries of early travellers can be used to lengthen the available climate records before instrumentation was in place (e.g. Nash and Endfield 2008).

15.4.4 Improve the Understanding of the Interactions of Ecogeomorphic Processes and People

The integration of biophysical processes that is represented by ecogeomorphology provides only a partial perspective on the problem of land degradation in drylands. A more complete perspective of the land-degradation problem must include socio-economic and political processes and their interactions with ecogeomorphological processes and patterns, as depicted in Fig. 15.1. In many ways the solution to this challenge is similar to that in Sect. 15.4.1 on the establishment of a common language. Part of the solution is to have integrated research projects in which the scientists from all disciplines fully engage in all aspects of the research and participate where feasible to gain an appreciation of the full range of different perspective involved as well as the broader scale context. Without understanding the politics, socio-cultural characteristics and economics of a region, it is impossible to determine suitable land-management strategies that will achieve the desired goals, and the amount of resources that a region might be able to invest to do so (e.g. Green and Lemon 1996). While some regions might be able to diversify, to reduce dependence on activities that exacerbate degradation, others may not, and these are the regions that need more creative solutions. However, there is a risk that fully interactive research projects become unmanageable due to the greater diversity of processes involved.

Given the importance of modelling for understanding large-scale changes (both in space and time), an integrated modelling framework that can include all of the mutual dynamics of all disciplines shown in Fig. 15.1, as contributory to understanding land degradation in drylands, is essential. In modelling, for example, an extension of continuum (differential) models that may be appropriate for the biophysical processes and patterns of ecogeomorphology will not usually be suitable for modelling socio-economic and political processes. However, simple rule-based approaches – the so-called "generative social science" approach (Epstein 2007) – have been demonstrated to be useful in this context. For example, Millington et al. (2008) used a rule-based approach to evaluate the different impacts that Spanish farmers with traditional versus modern worldviews have on vegetation and fire regimes, and thus their potential impacts on land degradation. There is a conceptual advantage with using this approach, using agent-based techniques, which strongly

overlap with the individual-based approaches used in many pattern-based models (Grimm and Railsback 2005). This sort of modelling approach also shows great potential for the integration of knowledge from different sources using participatory model building (e.g. Castella et al. 2005; Nguyen-Duc and Drogoul 2007), in which different stakeholders and experts are questioned in order to evaluate the key parameters and processes, or interact with initial versions of the model to evaluate its performance. However, given the qualitative modes of analysis in many aspects of social science, care must be taken in their application, evaluation and reporting. Millington et al. (2012) discuss ways in which narrative methods may be used to discuss and test the results of this sort of model, for example by acting as an intermediary between formal descriptions of model structure and quantitative analyses of model output. Twyman et al. (2011) note that there may often be a paradox in that the model analyses may be given too much emphasis by policy-makers because their quantitative nature may seem more "exact" than the qualitative aspects of the work (but see Chap. 10), while at the same at the same time as they are seen as incommensurate with qualitative techniques. They suggest that this paradox underlies a "healthy tension" between the two approaches that essentially improves both approaches through a triangulation of results, not least when scenario- and narrative-based methods underpin both aspects of the interdisciplinary research.

Thus, a commonality of approaches (complexity-based science, agent/individual-based modelling, narratives, triangulation) can be seen to underpin a common approach to the understanding of the human and environmental aspects of the land-degradation problem. It is exactly these sorts of methodological and conceptual advances that are needed to address the (interdisciplinary) scientific problems that are more fundamentally required to improve approaches to managing land-degradation problems.

15.4.5 *Develop Management Strategies for Combatting Land Degradation in Drylands*

Notwithstanding the gaps in our understanding of land degradation in drylands, there is a pressing need to use the integrated understanding discussed above to develop management strategies to stop, prevent or reverse this degradation. As it has been previously stated, the world's drylands are home to two billion of the world's population, including many of the poorest. Many of the world's drylands have undergone land degradation in the recent past affecting the livelihoods of 250 million people, and many are projected to be affected by further desertification in the coming decades as a result of climate change (Schlesinger et al. 1990; Okin et al. 2004). People cannot wait for scientists to formulate what they may consider to be an adequate explanation of land degradation before action can begin. Nor is this approach an appropriate model for the interaction of science and society. Rather, the management agenda is one that has to be developed in parallel with scientific

understanding. A symbiotic relationship between improved scientific understanding and improved management tools is one that will benefit both: developments in scientific understanding will be grounded in place and management will be at the forefront of scientific understanding. Implicit in such an approach is that there is not ONE scientific understanding of land degradation in drylands but that there are many that are both locationally and culturally contingent. That is not to say that there are not similarities across locations and cultures, but just that such similarities are not a *necessary* part of understanding land degradation.

If developing management strategies is to be symbiotic with developing scientific understanding, then this development needs to be an integral part of research programmes to improve scientific understanding. There are two challenges to this integration. First, to identify those management strategies that are compatible with the scientific understanding and, secondly, to have those strategies adopted by land users and managers. Unless the latter is achieved, then neither will the goal of developing strategies to combat land degradation be achieved, nor will the benefits of successful (or otherwise) evaluation of scientific understanding be possible.

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