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Landscape sensitivity: from theory to practice

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Abstract

Landscape sensitivity is expressed as the ratio of the change in a system to the change in a landscape component. The larger the ratio, the greater the sensitivity. An array of drivers of landscape change is reviewed, but there is seen to be little benefit in separating natural changes from human-induced changes: most change has a component of each, though there is a continuum from one extreme to the other.

Changes in the systems themselves are reviewed, including the increasing evidence for two or more system states being possible. Whilst one state may be preferred, there is no consensus on what kind of a landscape we want, or how aspects of that landscape can be manipulated to give us what we want. This is a field of research were really new ideas are wanted, and where interdisciplinary research should be the norm.

Keywords: Countryside management; Landscape change; Landscape sensitivity; Land-use change; Natural systems

1. Introduction

'Landscape sensitivity' is not an easy term to define (Thomas, 2000). It is perhaps best to start with thinking about landscape, the major natural systems that determine the structure of that landscape, and then the processes that modify these natural systems. It is, however, important to recognise that modifications, and their magnitudes, have both spatial and temporal components and that these components are integral to an understanding of sensitivity (Thomas, 2000). It is also true that there is a considerable body of case studies and theory that relate to component parts of landscape sensitivity. For example, geomorphic processes in Scotland have been presented by Gordon and Sutherland (1993), landscape change discussed by Bishop (1999) and ecological succession by Glenn-Lewis et al. (1992). Whereas many of the individual disciplines have been studied, the novel element is that they need to be brought together in the study of landscape sensitivity.

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A simple model is shown in Fig. 1. The central line includes a number of words that describe the components of a landscape; others could be added, such as 'air' or 'water' towards the left and 'microbes' towards the right. Below this line of words there are two interacting natural systems. Acting on the rocks and surface deposits are a series of physical systems, largely linked to the 'weathering' of rocks and the transport of sediments (Knox, 2000). Linked with the biosphere are the communities of plants and animals, the 'ecosystems'. The physical and biological systems interact most intimately in the soil and hence the two horizontal arrows overlap below the word 'soils'.

Above the landscape descriptors are the facets of system engineering; these are the factors that can really alter the landscape. The movement of water, usually in rivers, has been highlighted on a number of occasions, but air temperature can affect the structure of rocks. Plant roots can have implications, especially in fissured rock, and some animals can shape landscapes. An example is the beaver (*Castor* spp.) which builds dams that change the configuration of streams, forests and wetlands. This is more especially a characteristic of the American beaver (*C. canadensis*) than the Eurasian beaver (*C. fiber*). Perhaps more surprisingly the artefacts of a few animal species can be seen from space, as for example the hairy-nosed wombat (*Lasiorhinus latifrons*) in Australia (Löffler and Margules, 1980). However, it is people (*Homo sapiens*) that have the greatest potential to affect landscapes through the shaping of soil, the cutting of rock and the re-routing of rivers. The term 'system engineer' is used to describe any factor that can alter a system or create an entirely new system. For each of these one needs to ask how large a change can be made, and what is the magnitude of any response in all of the other landscape descriptors to that change?

The idea of sensitivity comes in relation to the ratio of the magnitude of change to the magnitude of the response to that change. This is analogous to calculus, where the change in a dependent variable in relation to a change in the descriptor variable

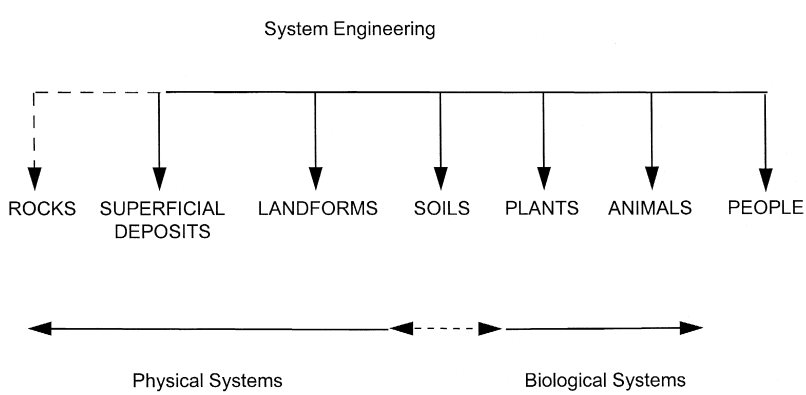

Fig. 1. A diagrammatic portrayal of landscape sensitivity. The various descriptors of landscape are shown in the central line of words. These are linked, as at the bottom, by two major series of systems that interact particularly strongly in the soil. Aspects of these descriptors can 'engineer' the system, shaping it in some sort of way, as indicated at the top. The concept of a 'system engineer' is explained in greater detail in the text.

($\Delta y/\Delta x$, or dy/dx when Δx is exceedingly small) is a measure of the sensitivity of the equation system.

Hence, the collection of papers in this volume contains a mixture of topics that explore the landscape descriptors, the two main natural systems that link these descriptors, and the 'engineers' that modify these systems. It is, however, the integration of all of these components that allows for a greater understanding of the subject of 'landscape sensitivity'. If S is that sensitivity, then a verbal equation summing this up is

$$S = \Delta(\text{change in system})/\Delta(\text{change in landscape descriptor}).$$

2. The drivers of landscape change

There are innumerable ways that changes to systems and changes to the landscape descriptors come about, and it is not always easy to separate out which is cause and which is effect. For example, Werritty and Leys (2000) asked when destabilization of rivers occurs; what are the factors responsible for some river systems being 'robust' whereas others are very 'responsive'? What are the feedback loops responsible for these differences? There are also effects of speed of change; with very long relaxation times, some systems that are studied today are still adjusting to changes in the past (e.g. Harvey, 2000).

Perhaps the starting point for many such questions is historical. The situation today has been inherited from the past. In the coastal environment this is very evident, and the processes that have occurred during the Holocene are extremely important in understanding the processes and coastal landscapes that we observe today (Hansom, 2000). This brings in the importance of the time dimension. What we observe now, or what we observe over a 3-year period, is just a short time slice through a process that has probably been occurring for hundreds or thousands of years, and which will continue into the future. Given the length of time over which landscape-scale processes operate, even a good historical record and current observations are short-term in comparison. Few studies on biological systems can reach the time-scale of Engelmark et al.'s (1998) 219-year post successional study on boreal forest. However, research on pollen or diatom deposits in sediments allows long time scales to be inferred and studied (Edwards 2000), as can studies of soil profiles and fossil assemblages.

As well as the dimensions of time and space, interactions need to be considered. In Fig. 1, there will be interactions within the physical systems at the lower left, within the biological systems at the lower right, and interactions between the physical and biological systems. Many examples of interactions have been given, such as Harvey (2000) on slope and channel in upland river systems, vegetation and grazing mammals (Miles et al., 2000), or the links between river flood plains and biodiversity (Petts, 2000). An example of a conceptual model for soils, that links these interactions with the human community, is given in Fig. 2. The human species is just one species out of tens of thousands of species that occupy any given area (for example, Usher (1997) estimated that there are of the order of 90,000 species in Scotland, defined as that area from the

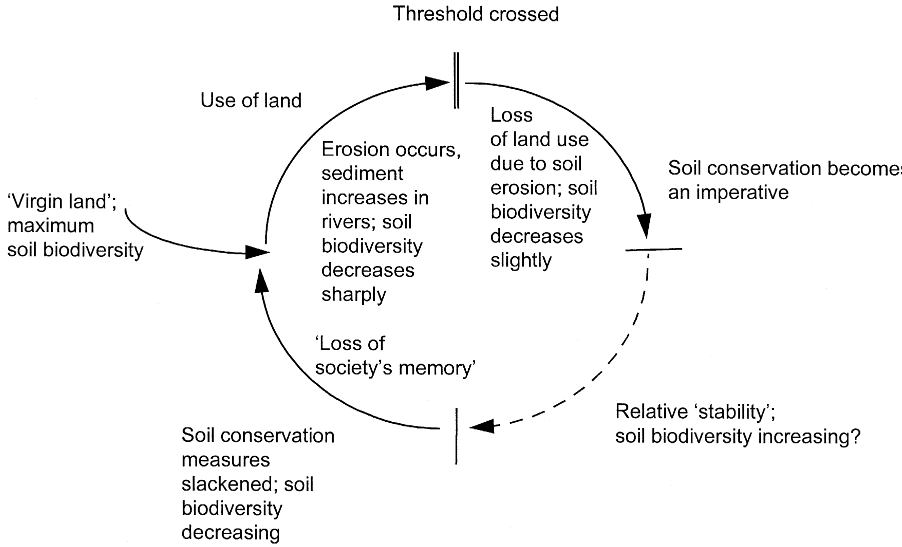

Fig. 2. A model, derived from a number of the conference talks, of the interactions between the physical and biological systems and the socio-economic context of the people using these systems. The model has been prepared for the soil, but the changes in soil biodiversity are still poorly understood. Of particular importance are the hypothesised reactions of a human society to change, and the perception that, after a period of landscape stability, there may be a loss of society's memory as to why various cultural practices have been used. The concept of thresholds is also discussed in the text.

12-mile seaward limit to the summit of the highest mountain), though it is the species with the greatest influence on landscapes. In going around the cycle in Fig. 2, interactions within and between the physical, biological and human social and economic systems are all too apparent, being driven by the ever-increasing size of the human population and the ever-increasing demand for resources by each member of the human population.

Amongst the drivers of change there is also the changing climate. The pertinent question that needs to be asked is 'what is normal?'. Climate change has greatly affected the landscape of Scotland over the 10,000 years or so since the ending of the last glaciation. The spatial variability in these changes has left Scotland with a very diverse series of geomorphological structures and processes (Gordon and Sutherland, 1993). There are still many unanswered questions such as how river systems will change under the current scenarios of climate change (Hulme and Jenkins, 1998). However, there are interactions here too. Milne and Hartley (2000) asked about the combined effects of a changing climate and nitrogen enrichment, whereas Werritty and Leys (2000) asked how different forms of land use might affect sensitivity. There are innumerable research questions that can be asked, but the real challenge will be in understanding the more generic questions and in finding ways of using the new knowledge in the management of many of the systems.

In all of this discussion, be it the threshold in Fig. 2 or nitrogen enrichment, there is a human dimension. Throughout the papers in this volume there are many other references to human impacts, be they due to land use, pollution or engineering works. However, the repeated reference to human impacts raised two further issues about the drivers of change.

One is the concept of ‘human sensitivity’; this is essentially due to land use change and water management activities changing the ‘natural sensitivity’ of hydrological processes and hence human reactions to change varying over time. This is one of the facets of the ‘loss of society’s memory’ or the ‘soil conservation becomes an imperative’ shown in Fig. 2. The second issue relates to whether there is a need to distinguish between natural and human impacts — this distinction was made by Edwards (2000) and Gordon et al. (2000). However, should there be a distinction? The human species is no less a natural species than an oak tree, a heather shrub, a red deer or a beaver, all naturally occurring species that have a greater or lesser effect on the structure of their environment. If a distinction is to be drawn, at what point in history or pre-history do people cease to be ‘natural’ (and presumably become ‘unnatural’)? Undoubtedly the human species is the one with the greatest impact on the landscape. If human impacts can be separated from all other (natural) impacts, this could prove to be important in the management of the countryside. For example, if erosion is a result of inherent slope instability, what can be gained by altering the stocking rate of grazing ungulates? It is perhaps in countryside management, where stability is an important consideration, that the distinction between human and non-human drivers of change needs most to be made.

3. Changes to the systems

Most processes are gradual, and hence they need to be studied over long periods of time. The palaeorecord is important, as it allows us to build histories from the last glaciation until modern times. The record allows processes of ecological succession to be assessed, erosion events to be detected, and, since the Industrial Revolution, the acidification of the environment to be determined. The importance of this palaeorecord is emphasised in the guidelines for selecting sites of geological and geomorphological importance in Great Britain (Ellis et al., 1996).

In reality, any system has a number of feedback loops (as emphasised by Knox, 2000). These may, or may not, make the system more stable. In general it might be thought that these feedback loops will maintain the system within some range of states. For example, in Fig. 3 a system could be considered to be in State A. This does not mean that it will be in the median position of state A all of the time (the solid horizontal line), but that it will vary within some limits, indicated by the horizontal dashed lines. Initially the trajectory in Fig. 3 stays comfortably within these limits.

Occasionally a threshold may be crossed, or an episodic or catastrophic event occurs, that forces the system into its alternative state, state B. In Fig. 3 this has been shown to have wider limits than state A, indicating that it is more variable. It might, just as equally, have been less variable or similarly variable. Knox (2000) has postulated that thresholds exist, and can ‘flip’ a system from one state to another. An example that has been worked out concerns shallow, freshwater lakes (Scheffer, 1997) where the two

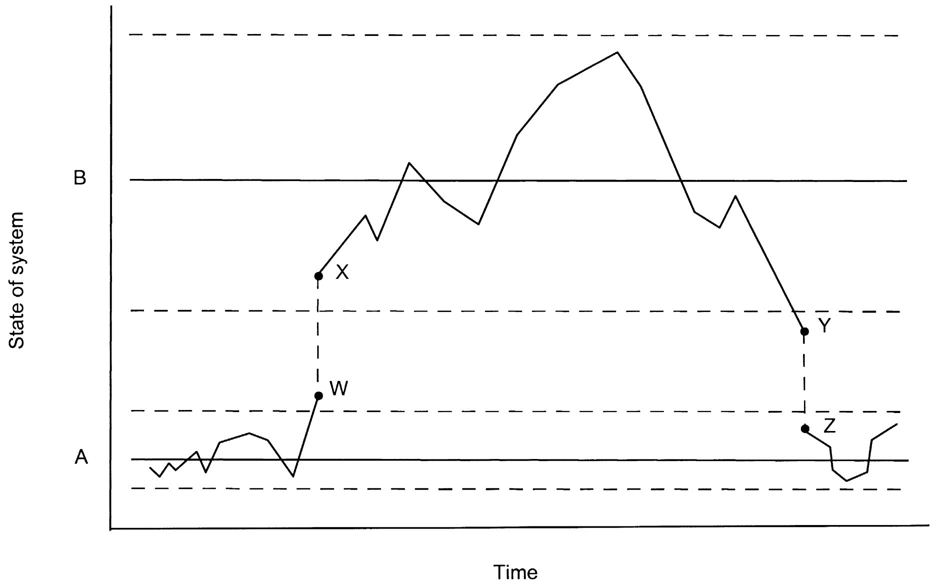

Fig. 3. A time trajectory of a hypothetical system through two states, labelled as A and B. The two continuous horizontal lines refer to the median levels of the two states, and the dashed lines indicate the variation expected through time about these median positions. The trajectory ‘flips’ between states at points W and X and Y and Z. A major research programme is needed to understand the factors that force (or perhaps trigger) a change from one state to another.

states consist of clear water in which there is an abundance of macrophytes and opaque water dominated by small algae. The mechanisms whereby the system ‘flips’ between these two states are as yet little understood, though it seems more difficult to flip from the opaque to the clear state than vice versa. Increasingly it is being recognised that many geomorphological systems (e.g. Schumm, 1979), as well as ecosystems, can have more than one stable state, though many systems are characterised by irreversibility when the cause of perturbation is removed (Sinclair, 1998).

This possibility of multiple states for a system raises many questions. How many possible states are there for any system, and what is the variation that can be expected within each of these states? What triggers a change from one state to another, and what is the mean return time before the system changes back again? How are these processes changed by the ‘System Engineers’ (see Fig. 1), and can practical management also be one of those ‘System Engineers’? It seems as if the essential aspect of any research is the need for a holistic view. Burt (2000) took such a view when he called for the management of whole catchments to be addressed. Similarly, Pethick’s (2000) analysis of coastal management in the face of sea level rise viewed the land–estuary–sea interfaces in a holistic way. Any practical discussion of ‘managed retreat’, responding to the consequential effects of sea level rise (French, 1999), will have to take a holistic view of the system, the drivers of change, and their sensitivities.

4. Application and ways forward

There is no doubt that many mistakes have been made. Simpson et al. (2000) have outlined the need to manage the grazings in Iceland so as to prevent massive erosion of soil and the loss of the vegetation cover. Work on coastal defences (Pethick, 2000) may alleviate a problem locally for a short period of time, but it probably exacerbates the problem somewhere else at the same time. The message is clear: we must learn the lesson that every landscape is sensitive to some degree and that we must use the land, the fresh water or the sea within the limits of that sensitivity. This gives rise to three interesting ideas.

The question is frequently asked "What sort of a countryside do we want?". The face of Scotland has been radically changed over the last 50 years (Mackey et al., 1998), with large increases in plantation forests, built-over land, bracken-dominated land and ditches. Losses have included the semi-natural habitats such as heather moorland, unimproved grassland and blanket mire, as well as deciduous woodland and hedgerows. What is the vision of the future, and how do we get politicians to respond to a vision? The support schemes for agriculture, forestry and rural development all exist, but all seem to drive change away from what many peoples' vision might be. How can we couple these support schemes to a realistic vision of what people want, of what changes would be beneficial to the environment of Scotland? It is here that the Local Biodiversity Action Plan process (Anonymous, 1999) brings more closely together the top–down approach of support schemes with the bottom-up approach of what local people actually want for their economic well-being.

Second, how do we influence the landscape of today to achieve at least a part of that vision? Burt (2000) felt that research is needed to explore the value of a buffer zone around rivers and streams so as to reduce pollution loads. Some targeted set-aside and woodland (or tree) planting in these riparian corridors could largely benefit the quality of freshwaters and the biodiversity that they are capable of supporting. We perhaps need more large-scale experimental areas where integrated and holistic research can be carried out at the landscape scale, looking at hydrological and biological processes, whilst at the same time exploring the effects of change on people's perception of landscape, aesthetics and the value of the countryside for recreation. An impressive start to such large-scale experimentation is located at Alnarp, in Sweden (Gustavsson, 1999), but it remains too early to gain definitive results of such combined scientific and sociological research.

Third, are there any really new things that we ought to do? Perhaps the most striking new landscape feature proposed was to start growing deltas on particularly vulnerable coastlines (Pethick, 2000). To stop long-shore drift and erosion on the east coast of England, Pethick's model predicted that it would be possible to grow a delta where even quite a small river emerged, and that this delta would protect land down-drift of it. It seemed a theory ripe for a practical trial, but perhaps problems of land ownership would mean that legally trained people may need to be involved with such an experiment. Are there other ideas that could make a system 'flip' to a more acceptable state (see Fig. 3), and perhaps to make it less sensitive to the drivers of change? Research on thresholds, and the factors that force a system to change from one state to another, is clearly a priority.

There are many potential items for research, but perhaps fewer ideas for the practical application of our existing knowledge and of the knowledge to be gained from the research underway at the present time. There is, however, one clear message that became apparent in many of the discussions. This is an imperative to get the priority themes of the conference across to decision makers. Brunsden's (2000) assessment of the sensitivity concept indicated that communication had to be achieved in simple ways. However, that does not mean that the ways have to be simplistic. The scientific rigour must be maintained, the breadth of experience documented, and decision makers, who deal with the various support and incentive schemes, informed about what is likely to be beneficial, either to the national economy of to the local economy. How to achieve that communication, the two-way interactions, is a question that is still to be answered. Indeed, it was suggested that the sponsors of this meeting should arrange at least one further meeting, not to air again the scientific, sociological and economic arguments, but to facilitate communication. Would a start be to work out the 'vision' for the national countryside — agriculture, forestry, coasts and freshwaters — for the forthcoming century? There could not be one single vision for the whole of the nation, but a spatial component will lead to a 'vision surface', with the vision changing according to how local conditions change. Herein lies a real opportunity to exploit the technology of Geographic Information Systems (GISs) to communicate the ideas of researchers to the policy makers and to local communities. However, the real challenge for the 2000s is how to achieve such a vision, get agreement on it, and then start to implement it.

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