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Geo-information needs: effects of scale

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The title of this paper could be interpreted as the demands that geo-information technology impose on the collection, processing and display of data for the planning of sustainable land management (SLM). Although geo-information technology does have limits in terms of volumes of data, speeds of processing or the development of clever computational algorithms, these must be seen in both fact and deed as subsidiary aspects of the problems of dealing with sustainability. In short, the geo-information tail should not be wagging the sustainability dog. So this paper examines the issues for SLM and then considers their geo-informational consequences.

A straightforward definition of SLM is "the reliable prediction of conditions that lead to sustainable forms of land use", which seems a slightly modified version of the aims of conventional land evaluation. Conventional land evaluation adopts a top-down, hierarchic approach [1, 7] identifying "natural and homogenous units of landscape/soil/biological conditions", which are described by a limited set of attributes or land characteristics that can be translated into land qualities which determine suitability (sustainability) for a given kind of land use or cover. The underlying paradigm of this approach has been called the "double crisp" model [6] because the classes in attribute space are supposedly completely definable and non-overlapping, and relate to discrete, uniform parts of the Earth's surfaces. The geo-information needs of this model are simple. They involve aerial photo or satellite image interpretation leading to the delineation of "objects" (homogeneous areas) in space which can be digitized in geographic information systems (GIS). The attributes are stored in linked relational tables and both attributes and mapped areas can be retrieved and recoloured using standard Boolean algebra or mathematical formulations of suitability or crop-performance algorithms [5]. The whole procedure can be carried out at any scale or level of resolution desired and spatial interactions are not (as yet) an important aspect of the analysis.

Although this procedure is common to many forms of geo-information handling, it is not particularly suitable for SLM for several reasons:

- spatial and temporal variation within the areas of land delineated are ignored
- spatial and temporal patterns may exist at several scales, not just at the level of resolution determined by the survey
- good decision making requires specific data and not data resulting from spatial generalization and reclassification and translation
- there is no understanding of the processes affecting the change or suitability of critical aspects of the land
- generalized top-down methods ignore local conditions
- the hierarchies and classifications used for aspects of the natural world do not necessarily have direct counterparts in the socio-economic fabric of land users.

So, the aim of this paper is to take a fresh look at these problems, in particular the meaning of the term "sustainable", and then the issues concerning the detection, sampling and characterization of spatial-temporal patterns that may affect the degree to which a "sustainable" solution can be found.

DEFINITIONS OF "SUSTAINABILITY"

Definitions of sustainability can be compared with the statistical concept of "stationarity"; both can have strict and relaxed forms. A strict definition of "sustainability" implies a closed system driven only by energy inputs from sources that are essentially limitless. True sustainability is an ideal, a holy grail, and unachievable because any real system, even the Earth, is open and in contact with its surroundings. Although change may be slow and difficult to detect, changes will and do occur. For example, Brouwer [2] demonstrated that the supposedly stable rainforest on impoverished white sand soils in Guyana receives substantial amounts of nutrients from the atmosphere, without which it could not function.

In practice, therefore, we are forced to adopt a definition of weak suitability, namely that the land management is as efficient as possible, minimizes waste and degradation, and provides a long-term stability for food production measured in terms of generations. The Second Law of Thermodynamics ensures that energy (and its surrogate forms) must be expended to bring this about.

We are therefore looking for ways to match or harmonize the demands of people with the limitations of landscape, such that serious imbalance will not occur. To do this, we need to:

- look at the sizes (or scales) of the various kinds of spatial pattern in the area of concern
- deal with problems of hierarchy
- look at issues of surveying—sampling and resolution
- examine problems of interpolating from point data to areas
- consider the processes causing spatial and temporal change.

The scales and structures of spatial patterns that can

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be perceived depend on whether we are
- looking at attributes of the landscape
- describing land use and land cover
- dealing with individual plants/organisms or vegetation communities/plantations.

Hierarchies are a convenient mental model for organizing complex information. The great advantage is that each level has about the same amount of detail (seven classes ± two) so you do not have to think hard when going to another level. The hierarchy of *library - book - chapter - paragraph - sentence - word - letter* is an ideal role model, which finds its counterpart in human land management (*country - state - province - local authority - local district - street - address*) but unfortunately not so clearly with the natural environment, where change and pattern occur at all scales. This is why different soil surveyors often cannot agree on where to draw boundaries (*cf* references in [5]). An alternative to the imposed hierarchy of nested, homogeneous mapping units is to adopt a paradigm of continuous variation of attributes over space.

Survey resolution and sample spacing are often constrained by the dimensions of a remote sensing scanner, the cartographic scale of a paper map or by the costs of sampling. Even geostatistical methods of analysis of spatial correlation structures are constrained by how the observations have been configured and distributed over space. Any sampling system is like a radio or television that is "tuned" to pick up a particular signal—the rest appears as "noise", an important point that is demonstrated both by Salvidor Dali's painting "Gaia", and by a geostatistical analysis of soil transect data in the Dutch polders (see [5]; pp 242-244).

When spatial data have incomplete coverage, they can be interpolated to fill the unsampled locations with "best estimates". Many methods are available and they all return different results, as is revealed by comparative studies (see [5], Chapters 5 and 6). Cost benefit studies (*ibid*, Chapter 10) show that the relations between sampling density or numbers and costs of data, the interpolation technique, and the reliability of the results are complex and depend strongly on how the sampled data tune in to the spatial patterns they are sampling.

Most of the above is not new, but people have been slow to recognize the importance of all the issues mentioned, from scales and hierarchies to interpolation. A major consideration that until recently has received little attention (simply because there were no tools) is the issue of the effects of spatial and temporal processes on land and land use practices. All the Earth's surface is affected by continuous change, which cumulatively has a bearing on the degree with which any given land management strategy is "sustainable". Change may be global (climate warming) or local (salinization, erosion); it may be gradual and difficult to observe (loss of soil by wind or water) or dramatic and catastrophic (earthquakes, volcanism, floods or landslides). Any system of land management for "sustainable" land use must take account of the possibilities and threats of both gradual and catastrophic change. This is where new, specially-developed geo-information systems are being used to model the possible effects of many different kinds of process on the natural resource base and the impacts and knock-on effects for human society. Some examples of dynamic models will be demonstrated during the lecture (for details see [4, 8] and the PCRaster website (www.frw.ruu.nl/pcraster.html)).

Geo-information and GIS are important tools for SLM, but they should not, nor do they need to drive the information collecting and processing activities. Rather we should:
- identify the physical and economic processes that control valuable (sustainable) land use
- identify the levels of spatial and temporal resolution, and the kinds of data needed to characterize these processes
- enquire if the necessary data have already been collected in a suitable form, and if so, obtain them
- if not, collect the required data, using the correct levels of resolution and sampling intensity
- then identify the kinds of geo-information tools needed for the job.

Note that none of this is preordained and the optimal solution for one location may not be the best for another. Remember that much data collection, storage, retrieval, analysis and presentation is not the work of objective, exactly programmed machines but is the result of a whole chain of human actions (*cf* [3; 5, Chapter 2]). The development of skills and the training of people with these skills is therefore of paramount importance if any kind of sustainability is to be reached.

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