

Scaling-Up: From Cell to Landscape

P.R. van Gardingen, G.M. Foody, P.J. Curran. Cambridge University Press, Cambridge, UK, 1997, 386 pp., US \$120.00, ISBN:0-521-47109-5 (Hardback).

Scaling has quickly become a buzzword in ecology in recent years as the emphasis of the field has clearly been shifting from fine to coarse scales. This research emphasis shift is inevitable for two reasons. First of all, it has become evident that most if not all environmental and resource management problems can only be dealt effectively with at broad scales (usually the human landscape and above). The second and more profound reason is that ecologists are now acutely aware that, in order to unravel how nature works, we must understand broad-scale pattern and process and relate them to those at fine scales with which we are most familiar. In both cases, transferring information from one scale to another, i.e. scaling, is indispensable. How to scale up or scale down? How does spatial and temporal heterogeneity affect scaling? How do different processes or ecological systems differ in terms of scaling? Are there general rules for scaling? These questions are central in all disciplines of earth sciences.

The book, 'Scaling-Up: From Cell to Landscape', edited by van Gardingen, Foody and Curran, is devoted to addressing the above questions. The book originated from an interdisciplinary meeting on scaling-up, organized by the Environmental Physiology Groups of the Society for Experimental Biology and the British Ecological Society which was held in April 1994. It has 18 chapters contributed by scholars in several disciplines of earth sciences, most of whom are from the UK and USA, with a few from Canada and Australia.

The first two chapters are rather general and relevant to all other chapters. The first chapter, by Curran et al., is a brief introduction to the concept of scale, and describes how this, sometimes confusing, term is used throughout the book. The authors point out the two rather different definitions of the word 'scale', which is now well known to most ecologists. The cartographic scale is the ratio of the distance between two points on the map to the distance between the same two points on the ground, whereas the 'colloquial scale' (sensu the authors) refers to the spatial and temporal coverage (extent) or the spatial and temporal resolution (closely related to grain) of a study. Obviously, the two meanings of the same word are conversely related. While some are apparently paranoid about the different usage of the word, thus advocating that only the cartographic definition should be used, this book adopts the colloquial definition of scale with a specifying adjective attached to it (e.g. leaf scale, field scale, regional scale, global scale). This is apparently consistent with the current literature. The second chapter, by Grace et al., is composed of nine propositions that are reflective of a diversity in the style of scientists and their intellectual processes. The authors of this chapter argue that broad-scale studies are not amenable to the classical scientific method of hypothesis testing through experimentation, and thus they are not well accepted by the scientific (particularly ecology) community. However, 'small things' alone cannot determine the characteristics of the living world. For example, a complete genetic map of a species would not in itself explain how the species evolved and why differences between individuals occur. Broad-scale studies often need different

approaches, and scaling-up will help reconcile different views within and between disciplines. These authors also point out the importance of explicitly recognizing the hierarchical structure of nature for scaling, but fall short in providing any details about how to determine appropriate hierarchical levels for scaling up particular processes.

In Chapter 3, Squire and Gibson argue that research often retreats from the scale and complexity of the real problem in order to get publishable results and that a much greater interaction is needed between researchers and policy makers. Chapter 4 by P. Atkinson discusses the importance of spatial autocorrelation and geostatistical tools and also describes a hierarchical sampling scheme that facilitates scaling (interpolation and extrapolation in particular). An excellent discussion on the role of remote sensing in scaling environmental processes using a nested-hierarchical approach is presented by Woodcock et al. in Chapter 5. Through an example from a forested region of the Sierra Nevada Mountains in California, these authors demonstrate how this hierarchical partitioning model can facilitate the derivation of landscape parameters from remote sensing data for environmental process models. Kruijt et al. explore the problems of leaf interactions and PAR (photosynthetically active radiation) absorption as well as non-linearity in photosynthesis and transpiration by comparing three simulation models (MAESTRO, SAIL, and a big leaf modes) that differ significantly in spatial details. Their results show that scaling from the leaf to canopy, which usually involves a great deal of spatial and mechanistic details, can be greatly simplified if the hypothesis of full acclimation of leaves to local PAR can be validated. Chapter 7 by Grime et al. describes a scaling-up protocol using plant functional types that are based on screening plants for their basic attributes of morphology, physiology and biochemistry and also on the CSR (competitors, stress tolerators and ruderals) plant strategy theory. Through four examples, the authors illustrate how this approach works and conclude that the CSR theory can help scaling up from plant species to communities and regional floras from an operational perspective.

Pathiness is ubiquitous even at the single leaf level and below. Weyers et al. in Chapter 8 describe the spatial and temporal heterogeneity of stomatal characteristics and related methods. Clearly, such heterogeneity affects photosynthesis and transpiration processes at the leaf level and thus have implications for scaling up. However, one has to wonder: how much fine-scale detail is needed to understand and predict large-scale phenomena? In a similar vein, Chapter 9 by D. Atkinson and Fogel documents the tremendous spatial and temporal variability in soils and their measurements, with a special emphasis on the root system and soil carbon budget. They conclude that root functional attributes are much more difficult to scale up than root biomass, and that our current ability to scale-up measurements of the mass and activity of plant roots and their associated microorganisms is rather limited. Barnsley et al. in Chapter 10 discuss the effects of sensor spatial resolution on, and alternative approaches to, scaling and generalization of land cover. In Chapter 11, Curran et al. describe how to relate remotely sensed data to biophysical variables and land cover, so as to estimate large-scale carbon budgets. Chapter 12 by Harding et al. explores possible errors that arise from linking GCMs (general circulation models) with SVAT (soil-vegetation-atmosphere transfer) models. They demonstrate that the

non-linearity in SVAT equations and landscape heterogeneity, among other factors, are very important in scaling up surface fluxes.

A stimulating discussion on variability, scale and scaling is given by Marshall et al. in Chapter 13, who claim that “both variability and scaling are always intrinsic to the system”. They conclude that “the distribution in magnitude of variability across spatial and temporal scales defines the correlations that are the basis of scaling laws”, and “determines the characteristic scales where the scaling laws change”. Chapter 14 by Russell and van Gardingen demonstrates that errors occur when crop models developed at the field scale are used at the regional scale. Lammers et al. in Chapter 15 present a modeling approach (Regional HydroEcological Simulation System, or RHESs) to scaling up ecosystem processes by aggregating land units into larger and more complex units, while incorporating the increased within-unit heterogeneity (higher frequency variations) as subgrid variability that is described statistically. Chapter 16 by Gurney and Sewell discusses the effect of temporal and spatial variation in evaporative fraction and energy budget at the surface of a prairie. Berry et al. in Chapter 17 present simulation results of scaling leaf-level biochemical and physiological processes to the canopy and then to the global scale using the SiB2 model. Finally, the editors conclude the book by providing a list of future needs and possible technological developments in scaling. As they point out, spatio-temporal heterogeneity and feedbacks and non-linearity in functional relationships present a grand challenge to scaling. In addition, socio-economic dimensions that are especially important to broad-scale processes must be considered in scaling up ecological and environmental processes.

Overall, the book covers various issues of scaling for a variety of processes, and calls for theoretical and methodological advancements of scaling across different disciplines. While it may appear to be disappointing to someone who is (naively) looking for general recipes for scaling up from the cell to landscape, this book does provide a diversity of views and methods on scaling. It offers more problems than solutions, but this is a rather accurate account of the state-of-the science of ecology regarding issues of scaling. Thus, I believe that all who are interested in the issues of scale and scaling will find this book useful. However, some fundamental scaling issues are not, or only superficially, addressed in the book. For example, how much detail needs to be incorporated or discarded for a given scaling purpose? How can one objectively identify, rather than subjectively impose, a hierarchical structure along which information is transferred? How many organizational levels or spatial scales does one need to consider in order to scale from the cell to the landscape? Is it even necessary or possible to scale from the cell to the landscape? It seems that answers to these questions are yet to be sought rigorously.

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