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Editorial

The ecology of scale

1. Introduction

The annual meeting in 2000 of the Resource Modeling Association (RMA) was held 26–30 June in Wageningen, The Netherlands. The RMA (www.resourcemodeling.org) is a group of scientists at the intersection of natural resource management, environmental science, and mathematics. The RMA is concerned with the application of quantitative methods, particularly mathematical models, to improve the understanding of natural processes, dynamics of wild populations, and human impacts on the natural environment.

This Special Issue reports about this annual meeting. We would like to express our gratitude to all contributors to the conference, to the authors of this Special Issue, and to the referees who were willing to take their time for detailed and constructive reviews. We are also grateful to Professor S.E. Jorgensen for his willingness to help in publishing this Special Issue. The financial support of KNAW (Netherlands Royal Academy of Sciences), ALW and WOTRO (Netherlands Foundation for Earth and Life Sciences and Netherlands Foundation for the Advancement of Tropical Research, respectively, both residing under the Netherlands Organisation for Scientific Research), Graduate School for Production Ecology and Resource Conservation, and Wageningen University is kindly acknowledged.

2. The ecology of scale

The conference was organised around the theme 'The Ecology of Scale'. Why 'The Ecology of Scale'? Faced with a complex world, ecologists tend to think about systems as organised at different hierarchical levels (e.g. organisms, populations, communities, ecosystems). It is often believed that any level of organisation has a distinct characteristic scale, and that different levels of organisation within a system can be recognised a priori. As a consequence, scales of observations and modelling are often pre-set, based on the a priori description of the system of study. However, moving up and down scales, dominant patterns and processes, and their hierarchies change. As a result, the hierarchical organisation that can be detected from data in cross-scale observations does not necessarily correspond to a priori levels. By pre-setting the scale of observation or modelling, important aspects of the system can be easily overlooked, and the resulting description about hierarchical organisation may be inadequate (Peterson and Parker, 1998). Processes and patterns can be better understood and described, if based on cross-scale observations or modelling. This is one of the great frontiers in ecology today and that is why this conference and Special Issue is focussed around this theme.

As the RMA is concerned with the human impacts of disturbance, exploitation, and develop-

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ment on the natural environment, one of the goals of the annual meetings is to discuss the application of models to resource management and its relevance for decision making. Natural resource modelling typically involves discrepancies between the scale of observation, model calculations and policy making. This is what Bierkens et al. (2000) in their book "*Upscaling and Downscaling Methods for Environmental Research*" called the problem of scale transfer, and they give many interesting examples. This problem is yet another reason that the issue of scale is the focal point of this Special Issue.

3. Some definitions

To avoid unnecessary confusion we think it is relevant to give some precise definitions. Our description follows the definitions of Bierkens et al. (2000) and Peterson and Parker (1998). Scale refers to temporal and spatial dimensions at which phenomena are observed in the field as well as in models. First of all, there is an area (e.g. m^2, ha, km^2) and time interval (e.g. days, years, decennia) over which observations are made and model outcomes are calculated. This is usually referred to as the spatial and temporal *extent* of an investigation. Both the area and the time interval can be divided into a finite number of sub-areas and sub-intervals. The surface area of these sub-areas and the length of these sub-intervals are called the *grain* of the observation. The grain is the smallest area or time period considered in an observation set or model, while it is the largest area or time period for which a certain variable of interest is considered homogenous. Only the average of the variable for these sub-areas or sub-intervals is known, and not the variation within. Increasing the grain is called *upscaling* and decreasing it is called *downscaling*. The term *cross-scale* is used when moving up and down scales.

4. The studies in this Special Issue

The studies in this Special Issue are shortly described below in the framework of the theme 'The Ecology of Scale', to demonstrate that upscaling and downscaling are important in natural resource modelling and analysis. Finally, some general lessons are extracted from the conference and the papers in this Special Issue.

4.1. Moving up and down scales

The notion that different levels of organisation can only be adequately described by observing phenomena at scales both above and below the focal level is stressed in the study of Heymans et al. By using Network Analysis, allowing for cross-scale investigation of quantitative interactions between different sub-components of ecosystems, they revealed that the presence of a vertical spatial dimension has important implications for functional properties of ecosystems such as diversity, resilience and productivity. Mooij et al. found by cross-scale model analysis that the dynamics of the Florida snail kite population strongly depend on the temporal interval and the spatial correlation between droughts. Van Noordwijk and Mulia provide an example of how to take self-similarity of aggregation patterns at different spatial scales into account by providing fractal-scaling rules for estimation of tree biomass. The Conversion of Land Use and its Effects (CLUE) modelling framework of Kok and Winograd is an example of a land-use model that incorporates what they call 'structural complexity', that is, taking different levels of spatio-temporal hierarchy into account. In their study about the quantitative effects of competition and plant dispersal dynamics, Matsinos and Troumbis demonstrated that two important characteristics determine the population dynamics and the final species composition in grassland communities, the intraspecific process of aggregation, and the coarse spatial patterns resulting from fine-scale local interactions between plant individuals. Tomlinson et al. showed that the profit curve for wildlife production rises far more steeply when increasing the spatial extent of the property size than it does for other land-use options such as subsistence production and commercial beef production. In their modelling study of belowground processes to explain field-scale emissions of nitrous oxide, Langeveld and Leffelaar assumed that the soil profile consisted of homogeneous soil layers (the soil layer being the grain of their research). They found that the N_2O profiles simulated did not correspond well to observed profiles and postulate that this problem may be solved by downscaling the grain of their research to the scale of the pores within the soil layers. Van Noordwijk found that by downscaling from the area that is defined by 'landscape' to the area that is defined as 'plot', the trade-off between local farmer's interest (crop productivity) and external stakeholders' interest (carbon stocks and biodiversity) may change.

4.2. The problem of scale transfer

The contribution of Fleming et al. recognises the problem of scale transfer between models developed at the fine spatial scale of experimental studies and the coarser scale for management decision making. Their study is an example of cross-scale model analysis and they demonstrate the scale-dependence of parameter estimates and qualitative behaviour of a spruce budworm population dynamics model. The study of Kumar et al. is an example of the problem of scale transfer between the analysis of a coarse grain observation set (km^2, days), and processes occurring at fine grain (m^2, h). Ideally, an observation set at this very fine grain would be needed to test their hypothesis, but this is practically impossible without drastically changing the extent of their research.

4.3. Other studies

The studies of Owen-Smith, Smallegange and Brunsting, McDonald et al. and Cromsigt et al. do not explicitly address the issue of scale, yet these are valuable and original contributions in the field of natural resource modelling. Owen-Smith developed a Growth, Metabolism and Mortality (GMM) model of herbivore-vegetation systems showing that dynamic stability can emerge from the adaptive response of consumers to spatial and temporal variability in resource availability and quality. Smallegange and Brunsting developed a dynamic model of the functional response, growth and grazing time of ruminants, and indicate that the quantity and quality of the vegetation, together with the animal's energy requirements, govern the daily intake of food. Indeed, as they acknowledge, a thorough understanding of local feeding ecology is necessary in order to be able to upscale to grazing rules that are valid for larger areas. The study of Cromsigt et al. demonstrates how models can be used to fit observed census values of wildlife, and these models are an important tool in decision making for the management of wildlife populations. The study of McDonald et al. compared optimal exploitation as derived from a stochastic population dynamics model with the actual exploitation of a pelagic fish stock, and they found that the fishery was economically overexploited over much of the period considered.

5. Conclusions

This Special Issue shows that enquiries into the issue of scale become increasingly important in the field of natural resource modelling and analysis. Further, it becomes clear from the studies presented here that results are scale-dependent, which can be discovered when moving up and down scales. To detect scale-dependent processes and patterns one depends on observation sets or model calculations of fine grain and large extent. However, collecting data of fine grain and large extent is generally costly and time-consuming. Therefore, often an a priori choice of a certain scale of observation and/or modelling is unavoidable. Clear understanding about the scale at which relevant processes operate is essential when choosing the appropriate scale of observation and modelling. A general guideline about how to choose an appropriate scale of study is that discrepancies between the scale of observation, dominant processes, and model calculations should be avoided. If this is not possible, these discrepancies should be explicitly acknowledged.

Summarising, at least three general lessons can be derived from this Special Issue. First, when regarding systems as organised at different hierarchical levels, one has to think, observe and model cross-scale. Second, thinking cross-scale means that one has to acknowledge scale transfer. Third, one has thus to explicitly define the grain and extent of the investigations.

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