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Self-organising map methods in integrated modelling of environmental and economic systems

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Abstract

The need for better techniques, tools and practices to analyse ecological and economic systems within an integrated framework has never been so great. Many institutions have made tremendous efforts in the implementation of sustainable environment management based on 'integrated' approaches, as opposed to that of late 20th century's in-depth knowledge or 'reductionism' concepts. However, achieving sustainable environment management seems remote, as our understanding of ecosystem response to human influence is insufficient to predict the environmental outcome of proposed development activities. This has left environmentalists and land developers wrangling over the reliability of current environmental modelling techniques, assessment methodologies and their results. As a result, ecosystems continue to deteriorate with commensurate biodiversity loss. The paper elaborates on how self-organising map (SOM) methodologies within the connectionist paradigms (connectionist paradigms refer to the late 20th century neural network architectures) of artificial neural networks (ANNs) could be applied to disparate data analysis at two different scales: regional (using river water quality monitoring data to evaluate ecosystem response to human influence) and global (for modelling of environmental and economic system data and trade-off analysis) within an integrated framework to inform sustainable environment management.

Keywords: Integrated modelling techniques; Ecological modelling; Artificial neural networks; Self-organising maps; Ecological data

1. Introduction

The need for better techniques, tools and practices to analyse ecological and economic systems within an integrated framework at wider scales has never been so great. Many environmentally concerned communities, scientists and international institutions, agree that better modelling techniques and tools are needed for an integrated analysis of human interaction with naturally evolving, highly complex and diverse ecosystems. This will allow humans and their activities to be sustained by natural systems (Graedel et al., 2001). The emphasis is on developing integrated interdisciplinary modelling techniques; an absolute contrast to the late 20th century's in-depth knowledge-based approaches. Many studies detailed in Section 2 reveal this fact. These studies elaborate on the environmental issues critical to human well-being with recommendations and measures for integrated analysis of ecological and economic indicators conducive to advancing co-ordinated efforts from a range of professionals to preserve our global ecosystem from further degradation. However, despite such efforts, policymakers and land developers continue to pay no attention to scientific predictions of the long-term detrimental effects to the environment, and argue about the reliability of current environmental impact assessment methods. This is due to a belief that environment sustainability invariably leads to

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socio-economic loss (Buckeridge and Tapp, 1999). Meanwhile, ecosystems continue to deteriorate with commensurate biodiversity loss (Reid, 2000). Thus, in practice achieving sustainable environmental management seems remote. The urgent need for new approaches to achieve sustainable environment management, the challenges faced in introducing interdisciplinary research efforts and the drawbacks with the current ecological modelling methods are explained. Thereafter, Kohonen's (1995) self-organising map (SOM) based artificial neural network (ANN) applications to integrated analysis of ecological and economic system data (at regional and global scales) are illustrated with examples.

2. Need for change

New modelling techniques, radical approaches and better rapport are considered to be of paramount importance for establishing better communication between the three main groups: scientists, policymakers and the general public. Vant (1999), Reid (2000), Clark et al. (2001) and Harris (2002), in essence, stressed the fact that better modelling tools with an integrated approach could play a significant role in enhancing a common trust between these different and equally important groups to preserve our global ecosystem for future generations. It is envisaged that new approaches could improve our understanding of diverse and complex ecosystem responses to a variety of human influenced and natural causes. The use of new tools to depict disparate data from different disciplines is the key factor in the efficient use of natural systems without any biodiversity loss or impact on continued ecosystem functioning, and is discussed in this section.

2.1. Changes in approaches and modelling techniques

The major changes required in modelling techniques are threefold: research efforts directed towards integrated interdisciplinary approaches; the inclusion of ecosystem forecast; and the use of slow response variables that are not incorporated into current modelling techniques.

Harris (2002) emphasised the need for integrated assessment and modelling (IAM) techniques to bring scientists, policymakers and society together in order to solve current global environmental issues. Currently, individuals of different professions consider scientific predictions that are based on highly complicated principles and hypotheses as beyond their comprehension and often ignore them (Clark et al., 2001). To make matters worse, scientists are becoming more focused on science and research, instead of improving their communication with the general public (Buckeridge, 2001). The knowledge divide is seen to be one of the main reasons for policymakers and the general public ignoring scientific predictions.

Clark et al. (2001) stated that continuous forecasts of ecosystem behaviour with suggestions for trade-off and alternative options based on evaluation and feedback analysis are vital for sustainable environmental management. They argue that current environmental problems, such as rapid change in climate and chemical cycles, depletion of natural resources supporting regional economies, proliferation of exotic species, spread of disease and deterioration of air, waters and soils, which pose unprecedented threats to human civilisation, are the results of poor planning and decision making of the past. Ecosystem responses reflected by so-called 'slow variables' could provide a significant cue to often cryptic ecological processes (Clark et al., 2001). Nonetheless, these slow ecosystem responses are not incorporated in current ecological modelling techniques. Their inclusion could provide a means to model the 'large inherent uncertainty' arising from strong non-linearities that lead to adverse impacts on an ecosystem. In current modelling terms such impacts are translated as 'being neutralised or mitigated'.

A similar approach could be seen in the early 1980s modelling efforts. For example, Mann (1982) stated that ecosystem modellers should focus on developing theories and models to establish the connection between the dynamics of populations and the behaviour of ecosystems. The analogy in statistical mechanics is the common connection between the motion of particles and the behaviour of a gas. The 'slow variables' in Clark et al. (2001) could be compared to the 'dynamics of populations' of Mann (1982) as an indicator of ecosystem behaviour. However, traditional approaches and techniques in ecology do not enable modellers to analyse processes which we have poor knowledge of, especially highly complex, slow variables or their responses. A similar dilemma encountered in industrial system monitoring and control was successfully overcome with the use of SOMs by modelling the measurable system variables, recorded online (Simula et al., 1998, 1999). Using this approach, Shanmuganathan et al. (2001) modelled the Long Bay–Okura Maine Reserve's intertidal monitoring data with inconsistent labelling to unravel the non-linear relationships within this system and its ecological dynamics.

2.2. New challenges in ecological data modelling

The transformation of large quantities of disparate data into simple, useable information is seen as a major challenge in many current environmental monitoring programmes. Vant (1999) identified two key aspects of this, namely, the identification of robust methods to summarise large volumes of data without losing the