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Modelling ecological and economic systems with STELLA: Part II

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Abstract

This special section contains a group of seven modelling studies covering a range of ecological and economic systems and problems. The models were all developed using STELLA, an icon-based programming language specifically designed for dynamic systems modelling. Models included in the special section cover: dinoflagellate (*Phiesteria piscicida*) dynamics as a result of coastal eutrophication, Menhaden fisheries management in the Chesapeake Bay, watershed characteristics affecting both brown trout habitat and beaver ponds, the impacts and economics of riparian buffer strips, the integrated ecology and economics of Brazilian mangroves, and the macroeconomy including natural resources and a range of critical assumptions about technical change and substitution. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

As interest increases in creating sustainable solutions to environmental and economic problems the need for methods of predicting the outcomes of policy decisions becomes more urgent. Where long term studies or experimental manipulations are not possible (as is often the case in complex ecological-economic systems) representative models can help to fill in knowledge gaps (Costanza et al., 1993). This special section of *Ecological Modelling* contains a series of models developed by relatively 'novice' modelers who built their models in a relatively short period of time to answer a wide range of questions about the ecological and/or economic systems they had been studying. It is the second in a series of special sections devoted to this topic[1].

All of the models were initially constructed during a seminar-style course at the University of Maryland at College Park between September and December, 1996. Participants were first intro-

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[1] See Costanza et al., 1998 for the first in the series.

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duced to the modelling program STELLA II and then individuals or groups chose a problem that each would explore over the rest of the term. The remainder of the class was spent in an open format where students provided one another with progress reports and feedback on their projects. Participants continued to work on their models after the course ended.

As one can see in this issue, the problems that concern researchers in the ecological and economic sciences are quite varied. Nonetheless, relatively simple models can provide a great deal of insight into the questions, ‘what is going on?’ or ‘what would happen if...?’ These models should obviously not be considered to be final answers to their associated complex questions, but instead as syntheses of existing information and guides or maps to direct future work.

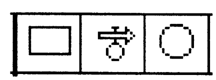
2. Modelling approaches

Scientists may be led to modelling for a number of reasons other than model creation for its own sake. Hall and Day (1977) consider three uses of models to scientists: understanding, assessing, and optimizing. Some of the models in this issue were developed by participants who simply wished to gain a conceptual picture of how a system of interest to them might work. In many cases, these types of models were generated before any field or laboratory studies had been conducted, and their main purpose was to examine what features are the most critical in determining system behaviour. At the next level, after empirical measurements had been taken, models were developed to test assumptions about the system. For example, in nutrient-dosing mesocosm experiments, models of the system can help researchers to determine pathways of nutrient flow that result in observed conditions over a period of time. Finally, along the lines of predicting system behaviour, some researchers want to know what conditions will lead to an optimal outcome of some property of the system. This type of analysis is essential to informed policy decisions and often cannot be performed without an integrated model of natural and manmade systems.

Many of the models presented in this section will be used as tools in ongoing investigations of the systems they describe. Some may be changed radically in structure or parameter sets after more empirical information about the system has been gathered. An important point about modelling is that it is an evolving process that sometimes requires one to discard early work and go back to the proverbial drawing board. Fortunately, as will be discussed in the next section, the STELLA modelling language makes this part of the process very easy.

3. Description of the STELLA modelling language

STELLA II is an object oriented programming language that uses an iconographic interface to facilitate construction of dynamic systems structures. The essential features of the system are defined in terms of stocks, flows and auxiliary parameters. The user places the icons for each of these features in the modelling area and makes the appropriate connections between features. The functional relationships between the features are then defined by the user. These relationships can be mathematical, logical, or graphical function, and the program allows quite a bit of flexibility here. STELLA II represents stocks, flows and parameters, respectively, with the following icons:



Connections between features are defined using ‘information arrows’ with the following icon:

The user generates a complete structure which would resemble the diagram depicted in Fig. 1. Stocks represent a reservoir of material such as population, biomass, nutrients, or money. Material flows between stocks or into and out of undefined sources and sinks (represented by ‘clouds’ at the ends of flow structures). Flows are

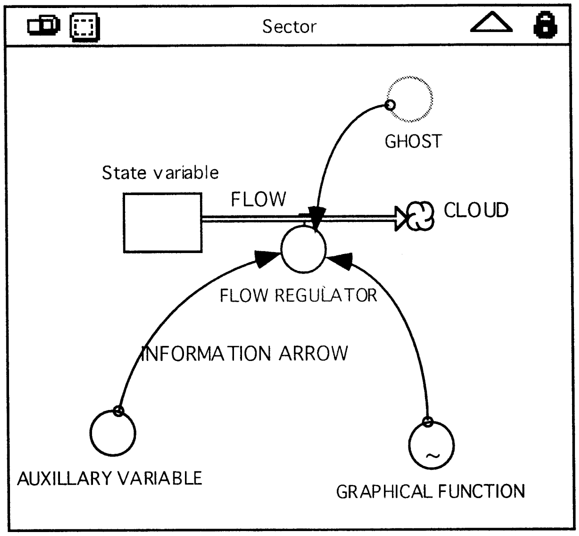


Fig. 1. A simple STELLA model showing the use of most of the symbols.

affected by auxiliary variables, stocks, and other flows through the use of information arrows. Auxiliary variables can take the form of constants, mathematical or graphical functions, and data sets. Once created, stocks and variables can be duplicated as 'ghosts' and used elsewhere in the model, thus avoiding a jumbled spaghetti of information arrows in the model. Portions of a larger model can be broken down into sectors which can be run independently or simultaneously to facilitate debugging. Details about how the user defines initial conditions, functional relationships, and parameter values, generates output, and performs sensitivity analyses are provided in other publications (Peterson and Richmond, 1996; Hannon and Ruth, 1994).

4. Summaries of individual contributions

There are seven contributions included in this special section, covering a range of ecological and economic systems and time and space scales. All of the models address some aspect of the interlinkage between ecological and economic systems.

Anderson (this volume) looks at the effects of seasonal variability on the germination and vertical transport of a cyst forming dinoflagellate. This type of dinoflagellate (*Phiesteria piscicida*) has been a huge problem in the Chesapeake Bay recently, causing direct economic losses to the fishing and tourism industries. Their life cycles are very complex, and the model explores the links between environmental factors and movement between life cycle stages in this class of organism. This model was an initial scoping of the problem and will be used to design more complex models and data sampling regimes. Nevertheless, the results are intriguing, and indicate the very complex dynamics that can result from the complex life cycle stages that these organisms possess.

Gottlieb (this volume) also addresses a problem in the Chesapeake Bay, namely the implications for management of nutrient removal in age-zero Atlantic menhaden. She looks at the dynamics of growth and consumption of age-zero menhaden during a 183 day period when they are abundant in the Bay. The model includes a fishery management submodel, and estimates the monetary value of the fishery, both as a traditional commodity and as the ecosystem service of nutrient cycling.

Jessup (this volume) moves upstream to look at brown trout dynamics and habitat quality in an urbanizing watershed. The model links land disturbing activities and the amount of impervious surface in the watershed to trout habitat quality, as affected by sediment transport, hydrology and water temperature. Results indicate that trout populations recover from construction events in watersheds with less than 15% imperviousness, but not in more densely developed watersheds.

Sturtevant (this volume) also investigates an important watershed issue in the Chesapeake Bay area; the dynamics of beaver impoundments. Beavers have made a strong comeback in the Chesapeake Bay drainage basin, and the model looks at the spatial and temporal dynamics of plant successional changes in a generalized beaver impoundment. Results show how changes in flooding regimes, sediment accumulation and seed sources (due to changes in watershed conditions) have dramatic effects on the spatial dynamics of beaver ponds.

Robles-Diaz-de-Leon and Nava-Tudela (this volume) look at an interesting proposed system of stream buffer management using *Asimina triloba* (pawpaw), a tree native to the Chesapeake Bay which can provide both a stream buffer and a marketable fruit. The model looks at the interlinked dynamics of growth, production, and possible economic gains from pawpaw planting in riparian buffers. The model shows how the economic viability of pawpaw planting depends on labor costs, the market value of the fruit, and the value of non-marketed sediment control services.

Grasso (this volume) moves a little further south and constructs an integrated ecological-economic model of mangrove systems in coastal Brazil, focusing on the trade-offs between forestry and fishery production. She combines the results of a simulation model with a dynamic optimization model of the system. The output of the simulation model was used in the optimization model to find shadow prices for the resources, which then affected the simulation model. Forest growth rates turned out to be the most important variable, since fishery production in this area is directly dependent on the mangrove forest.

Finally, Woodwell (this volume) looks at the whole ecological economic system, and the factors that affect the linkages between resource consumption and economic growth. The model is used to illustrate the dramatic effects of competing world views and assumptions on the results.

5. Conclusions

The models collected in this special section demonstrate the range of ecological and economic questions that can be productively addressed with easy-to-use dynamic modelling tools. The days of dynamic modelling as the purview of a few specialists are coming to a close. Dynamic modelling is now a tool accessible to researchers in many fields, as easily and routinely as statistics. Of course, the more powerful the tool, the greater the danger of its misuse. It is as important to understand the range of uses of models and their limits in these uses as it is to understand the technical details of the models themselves. This collection of models does an admirable job of using new modelling tools in appropriate ways to address important science and policy questions.

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