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Introduction to Special Issue

Ecological Modelling on modelling ecological and economic systems with STELLA

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Modelling of ecological and/or economic systems is a complex, yet essential, task. In recent years, improved modelling software and computer hardware have made at least the technical part of the task much easier. It is now possible to devote more of the modelling effort to using the model to understand the system rather than simply in coding and debugging the model. This increased ease of construction also helps prevent the modeler from 'falling in love' with the model, and allows changes in model structure to be more easily effected and their implications analyzed.

The papers in this special issue are the product of a graduate level modelling course/workshop held at the Department of Systems Ecology, Stockholm University, between September and December 1995. The course/workshop brought together a diverse group of researchers, each with a particular research question that could benefit from a dynamic modelling approach. Many of the participants had little or no previous modelling experience. Therefore, we needed a modelling package that would allow participants to begin modelling in a short time. There are various graphical programming languages available that are specifically designed to facilitate modelling of nonlinear, dynamic systems. Among the most versatile of these languages is the graphical programming language STELLA II (Costanza, 1987; Hannon and Ruth, 1994; Richmond and Peterson, 1994) which we employed in the course. STELLA II runs in both the Macintosh and MS-Windows environments and models created in either environment can run in the other. The language is described in a little more detail below.

The course was organised as an interactive workshop where there was little distinction between teacher and student. Several faculty and students participated. The first several sessions were an introduction to dynamic systems modelling and STELLA with several examples. Participants then began to 'learn by doing' by building their own models, either individually or in a team. Most of the remaining sessions

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were devoted to answering questions about modelling and STELLA, sharing progress on the modelling projects, and constructive feedback. Participants were expected to produce a ‘publishable’ project by the end of the course. This approach to teaching modelling seemed to work quite well even with the diversity of topics addressed by the participants. The production of this special issue is a testimony to the effectiveness of this approach to simulation modelling as both a research and learning tool.

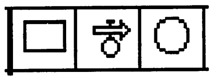
1. Modelling Approaches

In modelling ecological and economic systems, purposes can range from developing simple conceptual models, in order to provide a general understanding of system behavior, to detailed realistic applications aimed at evaluating specific policy proposals. It is inappropriate to judge this whole range of models by the same criteria. At minimum, the three criteria of *realism* (simulating system behavior in a qualitatively realistic way), *precision* (simulating behavior in a quantitatively precise way), and *generality* (representing a broad range of systems’ behaviors with the same model) are necessary. Holling (1964) first described the fundamental trade-offs in modelling between these three criteria. Later Holling (1966) and Levins (1966) expanded and further applied this classification. No single model can maximize all three of these goals and the choice of which objectives to pursue depends on the fundamental purposes of the model (Costanza et al., 1993).

Most (but not all) of the models presented in this special issue were aimed at developing basic understanding of the system’s dynamics and therefore emphasized generality over realism and precision. This does not preclude later versions of the models aimed toward more realism and precision, of course. In fact, general, or ‘scoping’, models can be seen as the logical first step in a multistep modelling process where the general model sets the stage for later, more precise and realistic research and management models (Costanza and Ruth, 1997).

2. Description of the STELLA Modelling Language

STELLA II is an object-oriented graphical programming language designed specifically for modelling dynamic systems. It requires that we identify the system’s state variables (or stocks), flows and parameters and establish the appropriate connections among them. An almost infinite variety of systems and dynamic relationships can be modelled with these simple building blocks. The symbols for stocks, flows and parameters are chosen with the mouse, placed on the screen, and connected with each other. STELLA II represents stocks, flows and parameters, respectively, with the following three symbols:



The structure of the model is established by connecting these symbols through ‘information arrows’

For example, Fig. 1 shows the use of all the symbols in a simple model. The state variables can be stocks of anything of interest in the model, for example, biomass, amount of nutrients, population, or capital. Flows can be between state variables (i.e. algae consumed by herbivores) or from/to a ‘cloud’ which represents an unlimited source or sink outside the model. Flows are affected (through the information arrow) by other flows and state variables or auxiliary variables (circles) which can be constants, the result of any sort of side calculation, or graphical functions showing empirical or hypothetical relationships. ‘Ghosts’ of a state variable, flow or parameter from another sector can be used to limit long connections across the model and improve the readability. The user can also specify named ‘sectors’ which can be run independently to aid debugging.

Once the structure of the model is laid out on the screen, initial conditions, parameter values and functional relationships can be specified by simply clicking on the icons for state variables, flows and parameters. Dialogue boxes appear that ask for the input of data or the specification of graphically or mathematically defined functions. A set of difference equations is generated through this process, which can be viewed and manipulated directly, or exported to other modelling environments (Maxwell and Costanza, 1995)

Equally easy is the generation of model output in tabular or graphical form through the choice of icons. Data can also be imported by copying and pasting from spreadsheets or other programs. Dynamic linkages to other programs can also be set up with the publish and subscribe function on the Macintosh. The STELLA 'authoring' function also provides methods to quickly generate a user friendly interface for the use of a model. For example, 'sliders' are available to enable a model user to alter model parameters as the model runs. Another dialogue box allows the user to select integration algorithms (Euler, Runga-Kutta 2 or Runga-Kutta 4) and to specify the time period of the model and the integration time step.

Model sensitivity to parameter changes can be assessed either by varying parameters with the sliders or using the built-in sensitivity analysis specified in another dialogue box. It allows the user to run the model a specified number of times while a selected parameter is incrementally changed. The result can be plotted in graphs showing the results from all runs.

3. Summaries of Individual Contributions

There are six contributions included in this special issue, covering a range of ecological and economic systems. The models also cover a range of time and space scales, from a single laboratory population of *Myaia mixta* over a one-year period, to the coastal zone of Patagonia over a 50 year period. A few of the models addressed multiple time and space scales and the interlinkages between ecological and economic systems.

Colding looked at food taboos as a mechanism to control hunting pressure in the Achuar of Brazil. He modelled both the local ecosystem and the human interaction with it. Preliminary results indicate that food taboos are indeed an effective means to achieve sustainable hunting patterns.

Troell and Norberg modelled an integrated salmon-mussel aquaculture system. The mussels are used to filter wastes from the salmon cages. They found that since mussel growth was usually

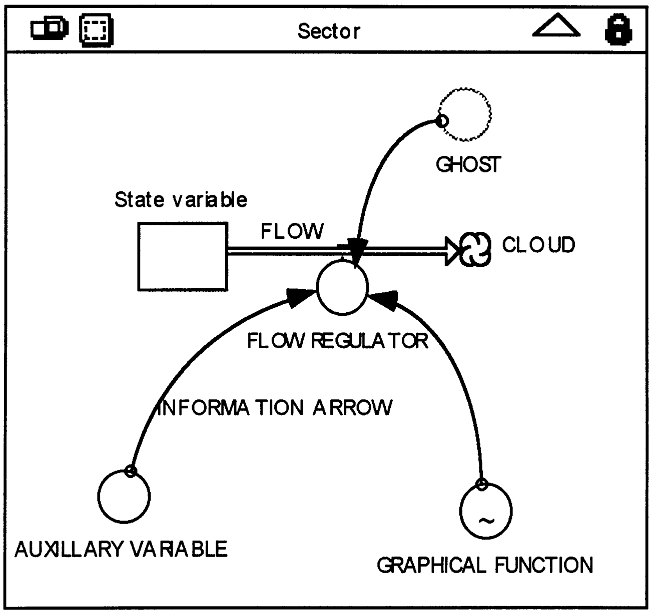


Fig. 1. A simple STELLA model showing the use of most of the symbols.

limited by seston concentrations, not suspended solids from the fish cages, and the fish waste came in short duration pulses which the mussels could not effectively use, that the linkage in the proposed system was ineffective for reducing local pollution. However, they also found that at a larger regional scale the integrated cultivation technique may work if the time and space scale issues are adequately resolved.

Duplisea examined the energy flow through a coastal benthic community incorporating feedbacks between biotic and abiotic state variables. The model was tested against field data and several scenarios involving seasonality in temperature and organic carbon input were considered. The modelling exercise successfully identified the main structural elements in the system and the gaps in existing knowledge.

Lindgren looked at the potential impacts of climate change on the incidence of tick-borne encephalitis (TBE) in Sweden. The model indicated that the incidence of TBE will increase in endemic regions in Sweden unless the annual vaccination rate is increased by 3–4 times.

Gorokhova modelled the growth and energy dynamics of *Mysis mixta*, and calibrated the model to experimental laboratory data. The model showed a very good match to the data once some revision of earlier literature estimates of key parameters was made based on the calibration.

Finally, van den Belt, Deutsch, and Jansson modelled the coastal zone of Patagonia using the model construction process itself to help build consensus among the various stakeholder groups. The model included sectors for penguins (a main tourist draw), hake and anchovies (major food items for penguins and also commercially harvested), coastal and offshore fisheries, the local and international fish markets, tourism, and oil pollution. The model looks at the linkages and trade-offs between these sectors and calculates the total net present value of the coastal zone under different future management scenarios. For example, overfishing harms not only the fisheries sectors, but also tourism through its impact on penguin populations. The model shows that preventing oil pollution is very cost effective since damage to tourism via penguin deaths far outweighs the cost of cleanup and prevention.

4. Conclusions

The models collected in this special issue demonstrate the range of ecological and economic questions that can be productively addressed with easy-to-use 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, we believe, does an admirable job of using new modelling tools in appropriate ways to address pressing science and policy questions.

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