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Chapter 31

USING SIMULATION TO INTRODUCE THE SYSTEMS APPROACH IN EDUCATION

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Abstract. This chapter describes a way to teach introductory systems ecology and simulation with the program EXTEND. A library of systems blocks with pictorial icons was programmed. When the blocks are assembled and connected on a Macintosh screen, equations are automatically set up for simulation. By connecting the symbols with a mouse, students may build systems, set some initial conditions, and study the consequences of their arrangements.

Introduction

As our responsibility for the environment of the planet Earth increases, more teaching must concern the earth system and what we can do to sustain it. To make reasonable decisions, students need to understand how global and local ecological systems interact with economic systems.

An effective way to teach systems is for students to make models and computer simulations to gain understanding of the way that components interact and how the system as a whole operates. The steps to do this are straightforward: First, we make models of the ecological and economic systems. We test the models to see whether they act like the real systems in nature and the economy. If they do, we disturb them, as humans have disturbed the real systems. Then, we try various solutions to the problems that we have generated with the models. All during the process, we check our accuracy against observations and experience. Finally, we can make recommendations for policy changes.

This method of making and using models is useful for teaching principles of science and systems, as well as how to approach practical problem solving in the environment and economics. The kinds of public policy suggestions that come from the models can be discussed in classrooms and even, in some cases, used in the "real world."

A new computer simulation program, EXTEND, makes it easy to experiment with models on the Macintosh computer. A mouse is used to connect icons on the screen. After the model is drawn, simulation graphs are produced. The effects of various changes can then be shown by making "what if" changes in the program. In this chapter, we will show three examples of models of natural systems that are disturbed by humans.

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Overfishing: A Sample Model

We will build a model of a pond ecosystem, show how it functions naturally, and then demonstrate how it changes when it is overfished. Figure 31.1 is a picture of a pond ecosystem. First, EXTEND is called up on the Macintosh along with a library of ecological program blocks that we have prepared. With the use of a mouse, picture icons representing the parts of the system are drawn on the screen from our library and connected.

The resulting pond model is in Figure 31.2. When you click on each icon, a dialog box appears in which you enter the appropriate numbers, as in Figure 31.3, where you can change the quantity of sunlight. When all the numbers are entered, you tell the program to run the simulation that plots the changes in bond life (an aggregate of the lower food chain), sunfish, and bass over time (Figure 31.4).

Then we add an icon of people fishing for the bass (Figure 31.5). When the program is plotted after fishing is started (Figure 31.6), the quantity of bass goes down, bringing the fishing yield down. Note the data table under the graph; it keeps track of weights of components with time.

To conduct "what if" experiments, various changes can now be made. For example, if you spent three times more hours fishing, how would this affect your bass catch and the quantity of bass left in the pond? Compare Figure 31.7, which represents a simulation with three times the fishing effort, with Figure 31.6.

This fishing model can be adapted to any fishing situation—the overfishing of tuna in the Pacific or redfish in the Gulf of Maine. Appropriate numbers for producers and consumers in each system are put into the dialog boxes.

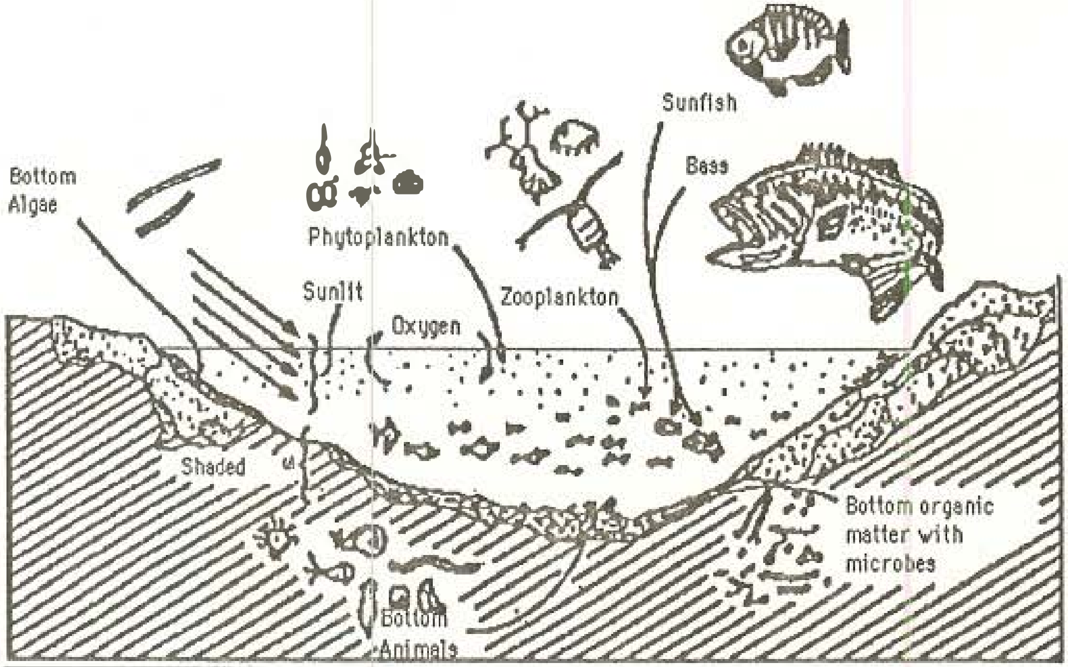


Figure 31.1 Picture of the 1 ha pond showing phytoplankton, zooplankton, plants, small bottom animals, sunfish, bass, and microbes.

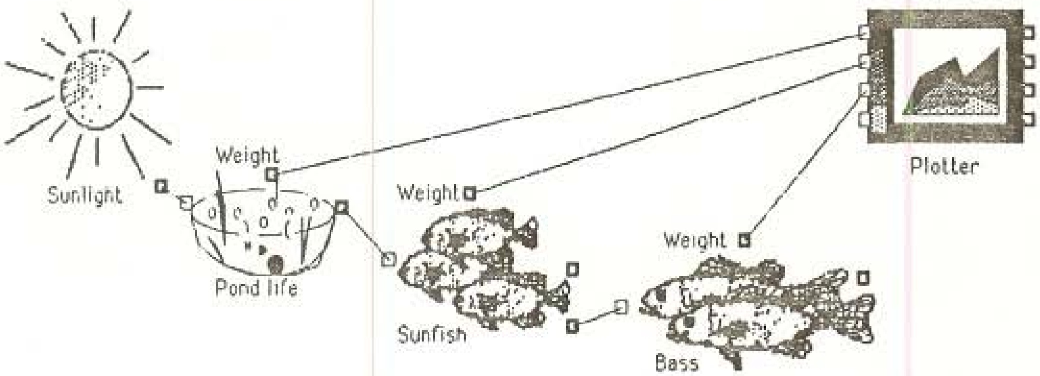


Figure 31.2 Picture icon ecosystem with sun, pond life, sunfish, and bass.

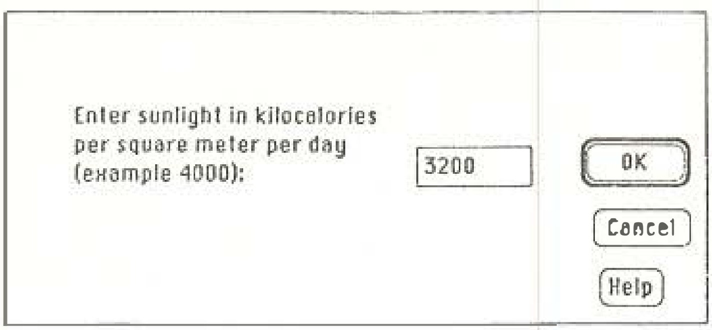


Figure 31.3 Dialog box of sun icon.

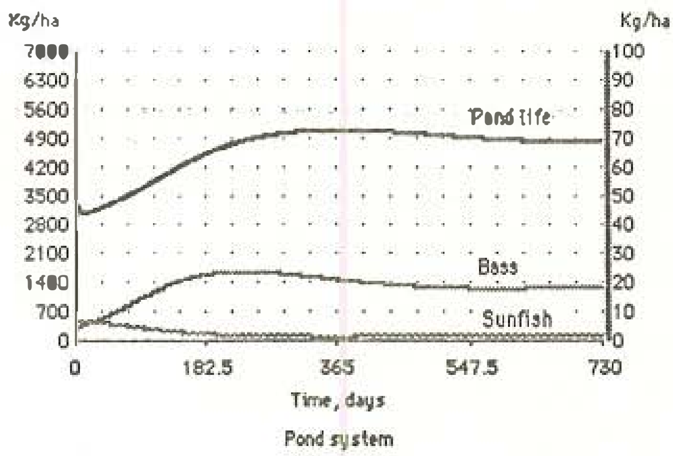


Figure 31.4 Graph of growth of pond life, sunfish, and bass.

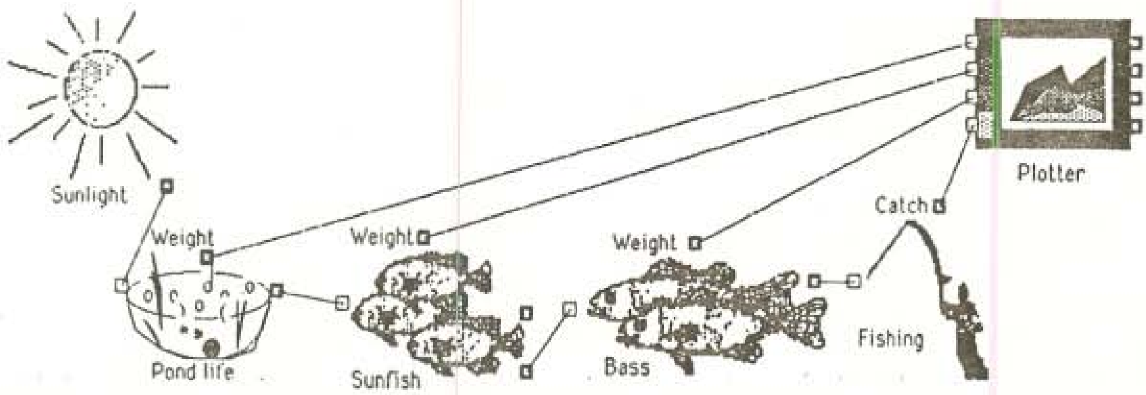
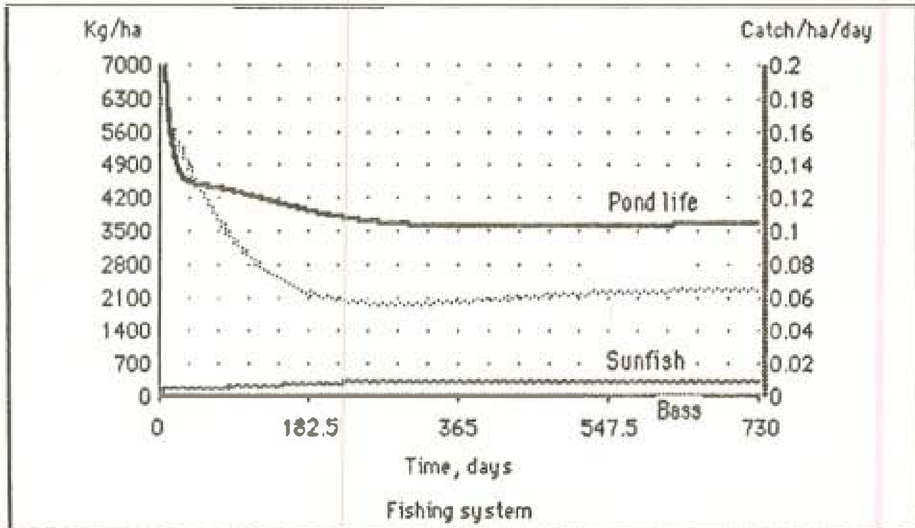


Figure 31.5 Picture icon ecosystem with fishing.



Time, days	Pondlife weight	Sunfish weight	Bass weight	Bass catch/day
0	9116.038	111.7772	18.0046	0.18
0.73	8732.884	115.0491	17.88094	0.180046
1.46	8377.594	118.0964	17.75933	0.1788094
2.19	8050.037	120.9483	17.64053	0.1775933
2.92	7748.313	123.6097	17.52437	0.1764053

Figure 31.6 Graph of changes in quantity of pond life, sunfish, bass, and bass catch.

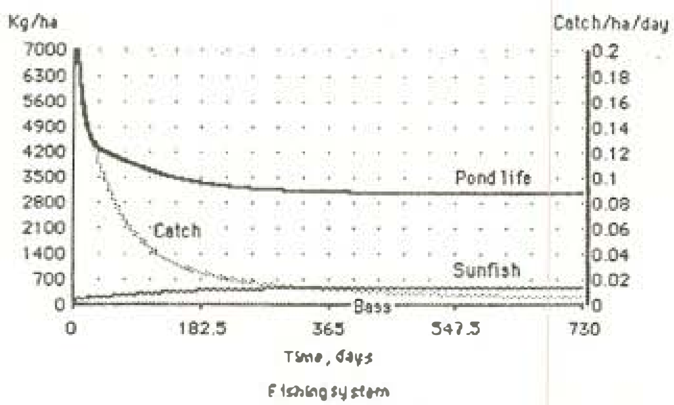


Figure 31.7 Simulation of fishing model with three times the fishing effort.

Principles of Environmental Systems

This modeling process demonstrates principles of environmental systems as well as illustrating real environmental situations. For example, zooplankton in Lake Michigan decreased when Lake Trout died out.

The most important principle is that of interdependence: systems and parts of systems interact with and affect one another. In the pond, energy from the sun flows into the pond to stimulate photosynthesis of algae and water plants, which in turn are eaten by small invertebrates. The energy from these small animals is consumed by the sunfish and then by the bass. Wastes from the animals are returned to the water to be used as nutrients by the plants.

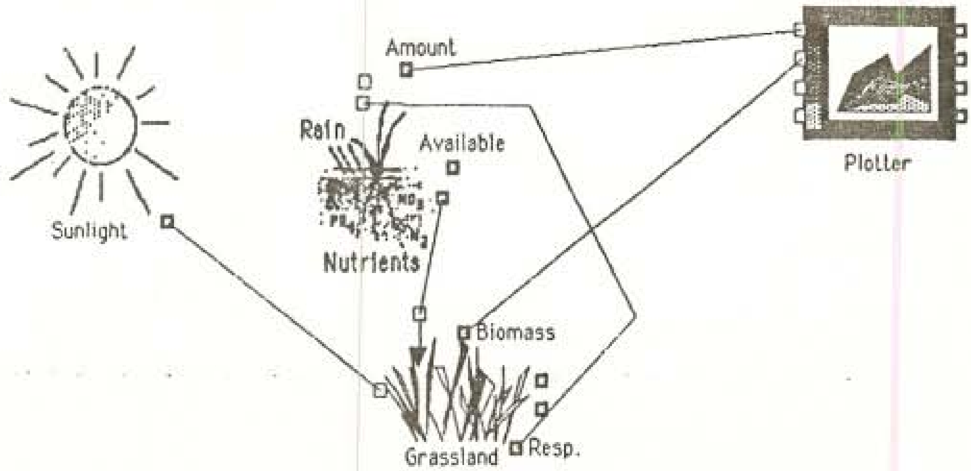


Figure 31.8 Model of grassland with sun, grassland, and nutrients.

Food webs can illustrate the principle of *hierarchy*, where many small items support and are controlled by fewer large items. In the pond example (Figure 31.5), many small photons of sunlight on the left are concentrated by the web to fewer bass at the right. Organisms with faster turnover time (shorter lives) are on the left, and larger organisms with slower turnover time on the right. Hierarchy is found in all systems, with the top of the hierarchy controlling the next unit below it. The energy of the sunfish is consumed by the bass, and the bass exert control on the quantity and quality of the sunfish. At the top of the hierarchy in Figure 31.5, the fishermen control the quantity of bass.

The quantities used in the models illustrate *the first and second laws of thermodynamics*. The first law states that energy changes form but, because it is conserved, can always be calculated. For example, 803 kc of sunfish make 93 kc of bass, with 710 kc going out of the system in waste heat. These figures also illustrate the second law, which states that in every process, some energy is lost as waste heat.

A characteristic of all enduring systems is their capacity to *recycle*, as illustrated in a model of a grassland system (Figure 31.8). Respiration of grassland creatures produces inorganic nutrients that recycle back to be used by the grass in photosynthesis. Materials flow around the system, with wastes from one part of the system that are necessary for production of another part being returned for use.

For a system to remain healthy, all products must recycle and be used by some part of the system. If wastes are not reused, the system will not last. The buildup of waste is one of our most serious human environmental problems. This suggests to us that if a product or chemical cannot be recycled, it should not even be made.

Chemical processes are also illustrated by the diagrams, such as *photosynthesis* by plants and *respiration* by all living organisms.

A Logging Model

Another environmental problem that can be examined with a model and simulation is cutting logs in forests. The question about forests across the United States and the world is the same as the fishing question. How much resource can be taken from the natural system and still keep it healthy and sustainable?

Economic exchange of money for sales and purchases can be included, as in the logging model of Figure 31.9.

A simulation of the logging system over 100 yr is shown in Figure 31.10. You can look at the results from different points of view. If you are a conservationist, you may be upset because the forest never grows back to its original biomass. If you are a forest products company manager, you will be more interested in the money to be made with the yield after 5 yr. The owner or investor may be interested in the long-run profit to be made.

In this model, the effects of changes of prices can be simulated in "what if" experiments. For example, what will the yield of logs and money return be if the selling price for logs doubles? Figure 31.10 shows the results of the model run with original prices and quantities, and Figure 31.11 shows the changes after doubling the price of logs. The growth of the forest stays low, but yield and profits go up.

Discussion of this model leads to broader, international trade questions. If these logs are being exported to Japan, is it to our advantage or to theirs? If we sell our logs to Japan and spend the money to buy Japanese goods, this trade is equal in money. But in Japan, the average quantity of goods that people can buy for the dollar is less than in the United States: the same dollar buys more here than there. Therefore, when you look at the exchange of real goods, the trade is to Japan's advantage.

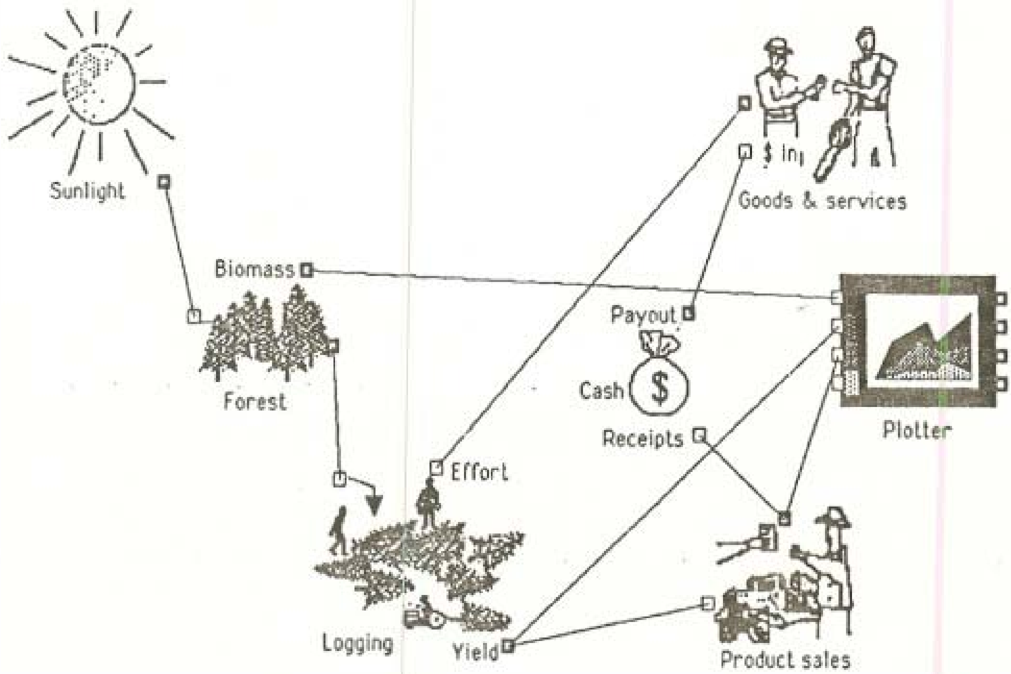


Figure 31.9 Model of logging system, with sun, forest, logging, product sales, cash, and goods and services.

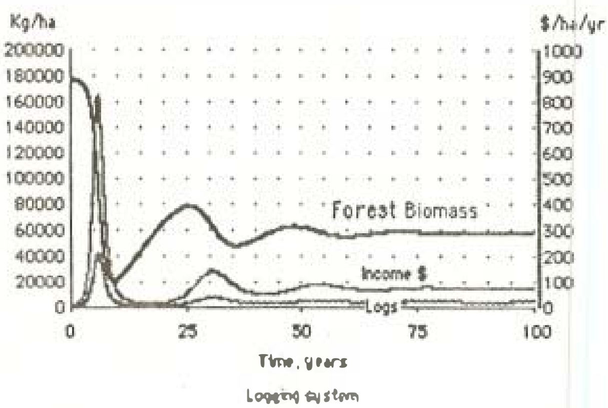


Figure 31.10 Simulation of logging model.

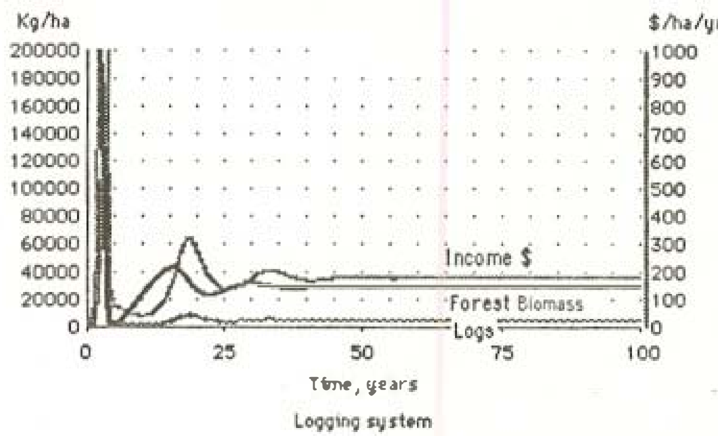


Figure 31.11 Simulation of logging model with the selling price of logs doubled.

Models with General Symbols

All these environmental and economic models have the same components and processes. The energy systems language, Figure 31.12, has general symbols that can be used for drawing models of any system. The pond system shown with icons in Figure 31.5 is drawn with the general symbols in Figure 31.13. The logging model is shown in Figure 31.14. Computer programs for these models can also be written in BASIC on any computer.

Summary

We present a systems method of learning how to consider and solve ecological and economic problems. An overall systems approach, using critical thinking and computer technology, is proposed to help students learn. Just as important, it is a method for scientists to discover and recommend logical and practical solutions to environmental and economic problems. More complex models of these systems exist whose results can be compared with these.

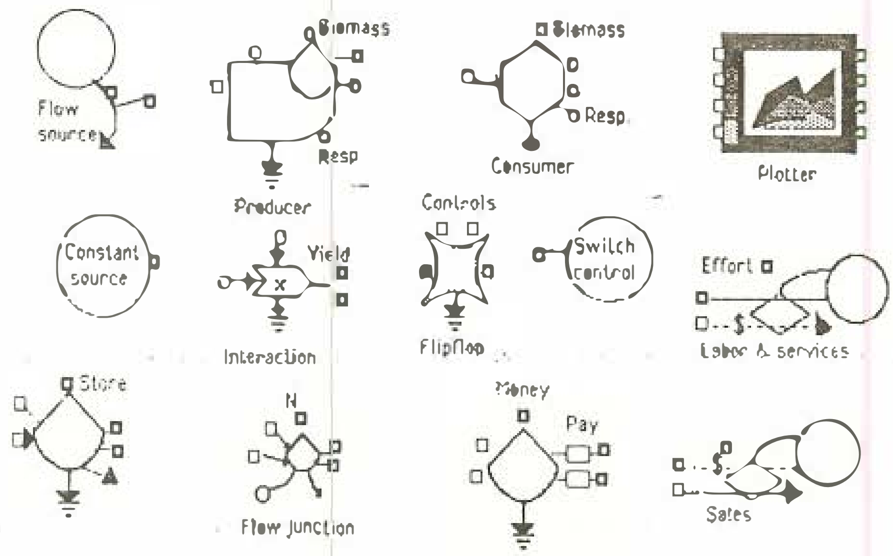


Figure 31.12 General system symbols.

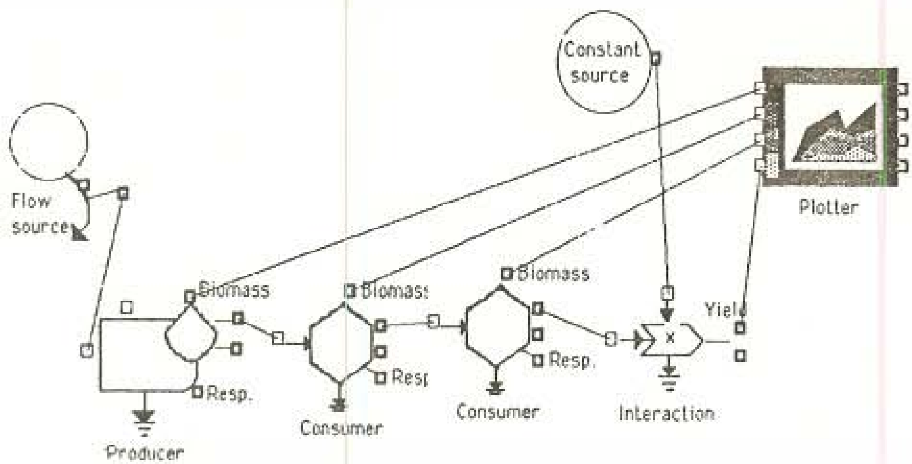


Figure 31.13 Pond system model (Figure 31.5) using general symbols.

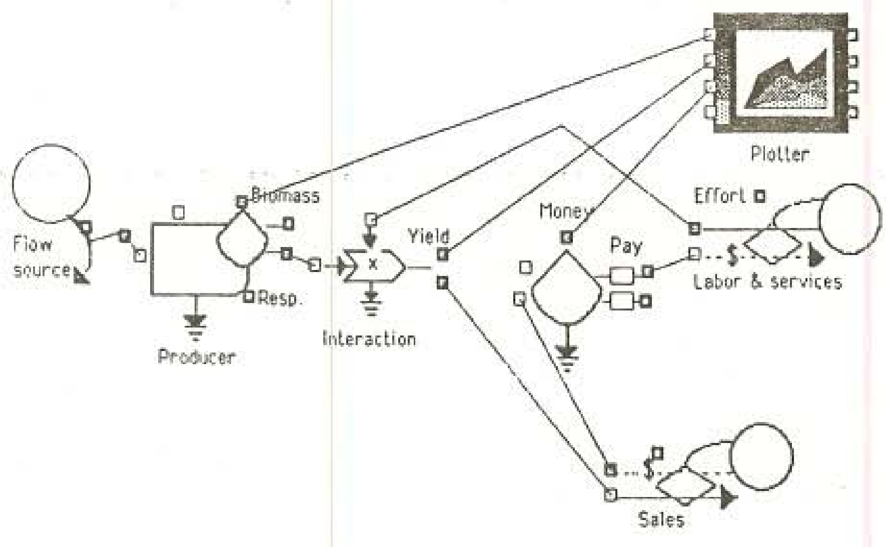


Figure 31.14 Logging system model (Figure 31.9) using general symbols.

This chapter describes the new approach but does not give enough detail to teach it or do it without more specifics. Teaching materials and other pertinent literature are listed at the end of the chapter.

Notes

1. EXTEND is a general purpose simulation modeling program available from Imagine That, Inc., 6830 Via Del Oro, Suite 230, San Jose, CA 95119 (408) 365-0305.
2. This work was done as part of the BioQUEST (Quality Undergraduate Educational Simulations and Tools in Biology) project. Text and programs of the Environmental Decision Making module are available on disks from BioQUEST, Department of Biology, Beloit College, 700 College St., Beloit WI 53511. These items are available commercially as part of BioQUEST CD ROM from Academic Software Development Group, Computer Science Center, College Park, MD 20742, (301) 405-7600.

Pertinent Literature

Odum, H. T. 1971. *Environment, Power and Society.* John Wiley, New York. 331 pp.

Odum, E. C., and H. T. Odum. 1980. Energy systems and environmental education. Pages 213–229 in *Environmental Education.* T. S. Bakshi and Z. Naveh (eds.). Plenum Press, New York.

Odum, H. T., and E. C. Odum. 1982. *Energy Basis for Man and Nature.* (Second edition). McGraw-Hill, New York, 330 pp. (College text).

Odum, H. T. 1994. *Ecological and General Systems* (formerly *Systems Ecology*). (revised edition). University Press of Colorado, Niwot. (Graduate text).

Odum, H. T. 1986. Unifying education with environmental systems overviews. Pages 181–199 in *Environmental Science, Teaching and Practice. Proceedings of the 3rd International Conference on the Nature and Teaching of Environmental Studies and Sciences in Higher Education,* Sunderland Polytechnic, UK. (Explanation written for engineers).

Odum, H. T., E. C. Odum, and M. T. Brown. 1993. *Environment and Society in Florida.* Center for Wetlands, University of Florida, Gainesville. (Introductory texts).

Odum, H. T., E. C. Odum, M. T. Brown, D. LaHart, C. Bersok, J. Sendzimir, G. B. Scott, D. Scienceman, and N. Meith. 1988. *H. T. Odum: Energy, Environment and Public Policy, A Guide to the Analysis of Systems.* UNEP Regional Seas Reports and Studies No. 95. United Nations Environmental Programme, Nairobi, Kenya, 109 pp. (Introductory text for international use with examples from other countries).

Odum, H. T., and E. C. Odum. 1989. *Computer Minimodels and Simulation Exercises.* Center for Wetlands, Phelps Laboratory, University of Florida, Gainesville, 319 pp. (46 models with simulation programs in BASIC, available for Apple II, PC, or Macintosh. The Macintosh disk also includes some EXTEND models. Plastic template for drawing general symbols is also available).

Odum, H. T. 1989. Simulation models of ecological economics developed with energy language methods. *Simulation,* August:69–75.

Lan, Shengfang. 1993. Chinese translation of Odum, H. T. *Energy, Environment and Public Policy: A Guide to the Analysis of Systems.* Nengliang Huanjing Yu Jingji, Beijing, China, 232 pp.

Odum, H. T., and E. C. Odum. 1993. *Environmental Decision Making.* Macintosh Simulation Software published in CD-ROM, The BioQUEST Library, by Academic Software Development Group, University of Maryland, College Park, MD.

Beyers, R. J., and H. T. Odum. 1993. *Ecological Microcosms.* Springer-Verlag, New York, 555 pp.