Simulation and the Systems Approach

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As human responsibility for the environment of the Earth increases, more of us must learn how the Earth system functions and what we can do to sustain it. To make reasonable decisions, we need to understand how global and local ecological systems interact with economic systems.

An effective way to find solutions is to make models and computer simulations to gain understanding. First, we make models of the ecological and economic systems. We test the models to see if they act like the real systems in nature and the economy. If they do, we perturb them, as humans have perturbed the real systems. Then we try various solutions on the models. All during the process we check our accuracy against observation and experience. Finally, we can make recommendations for policy changes.

This method of making and running models is useful for teaching principles of science and systems, as well as how approaching practical problems in environment and economics. The kinds of public policy suggestions which come from the models can be discussed in classrooms and used in the "real world."

A new computer program, EXTEND, makes it easy to experiment with models on the Macintosh computer.[1] 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 article we will show how changes in natural systems which are disturbed by humans can be modeled and simulated using EXTEND.[2] This article describes the new approach but does not give enough detail to teach it or do it without more specifics. Teaching materials and references are listed at the end of the article.

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 over-fished. First, EXTEND is called up on the Macintosh along with a library of ecological program blocks which we prepared. Using a mouse, icons representing the parts of the system are called up on the screen from our library of ecological blocks and connected.

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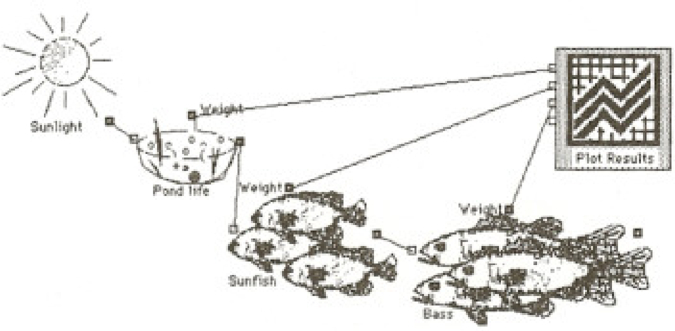


Figure 1

The resulting pond model is in Figure 1. When you click on each icon, a dialog box appears in which you enter the appropriate numbers, as in Figure 2 where you can change the quantity of sunlight. When all the numbers are entered, you tell the program to run the simulation, to plot the increase of pond life, sunfish, and bass (Figure 3).

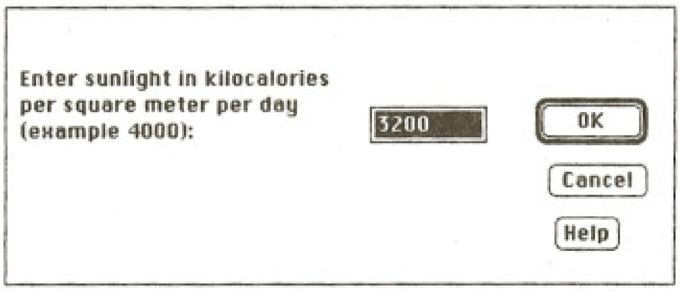


Figure 2

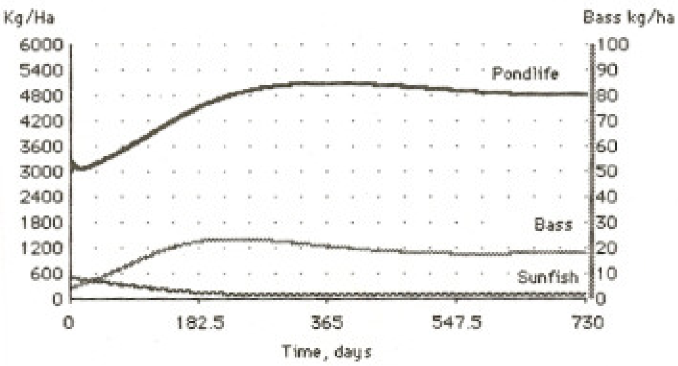


Figure 3

Then we add an icon of fishermen fishing the bass (Figure 4). When the program is plotted after fishing is started (Figure 5), 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.

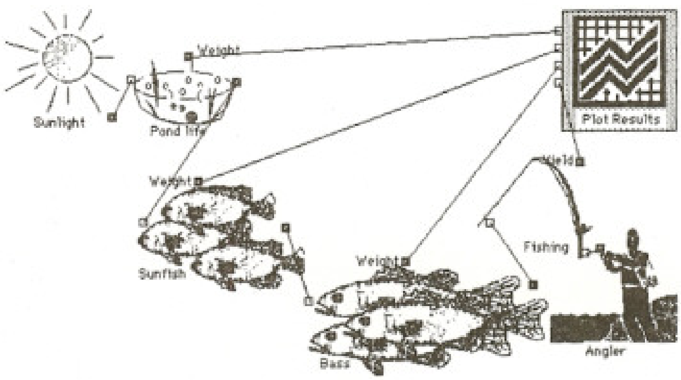
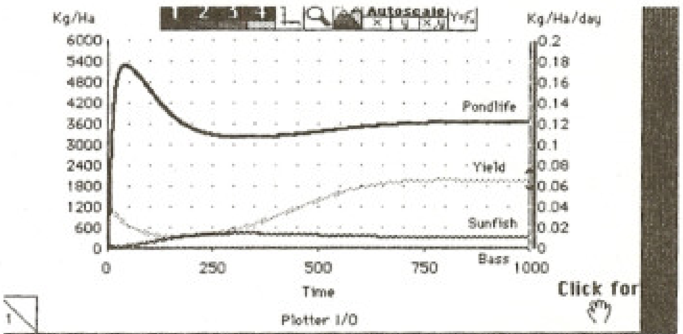


Figure 4



1000	3643.082	298.5999	6.397916	0.06398372
Time	Pondlife, weigh	Sunfish, weight	Bass, weight	Yield, weight
0	100	38.84	3.988	0
1	671.8182	37.77573	3.975805	0.03988
2	1185.655	36.93546	3.923555	0.03975805
3	1643.689	36.28431	3.871425	0.03923555

Figure 5

To conduct "what if" experiments, various changes can now be made. For example, if you spent five times more hours fishing, how would this affect your bass catch and the quantity of bass left in the pond? Compare the yield in Figure 6, with five times the fishing time as in Figure 5.

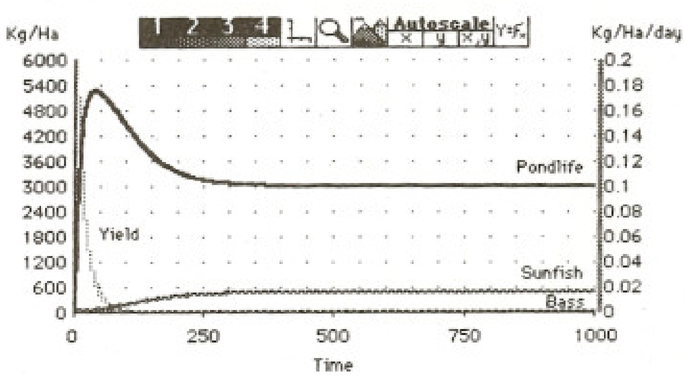


Figure 6

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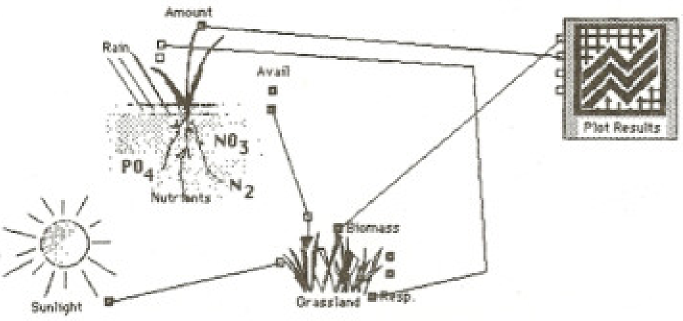

Figure 7

Principles of Environmental Systems

As well as illustrating real environmental situations, this modeling process demonstrates principles of environmental systems.

The most important principle is that of interdependence: systems and parts of systems interact with and affect each other. In the pond the sun flows into the pond to stimulate photosynthesis of algae and water plants, which are eaten by small invertebrates. The energy from this pond life is used by the sunfish and then by the bass. Wastes from the animals are used as nutrients by the plants.

Food webs can illustrate the principle of hierarchy, where many small items go to support and be controlled by fewer large items. In the pond example, many small photons of sunlight on the left in Figure 1 are concentrated up the web to fewer bass at the right. Organisms with faster turnover (shorter lives) are on the left and those larger and slower 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 control the quantity and quality of the sunfish. The top of the hierarchy in Figure 4, 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 can always be calculated, as 803 kilocalories of sunfish make 93 kilocalories of bass, with 710 kilocalories going out of the system in waste heat. These figures also illustrate the second law, which states that in every process energy is depreciated as waste heat.

A characteristic of all systems which survive is recycling. A model of a grassland system illustrates recycling. Follow the icon diagram in Figure 7. Respiration of grassland creatures produces inorganic nutrients which recycle back to be used by the grass in photosynthesis. Materials flow around the system, with wastes from one part of the system necessary for production of another part.

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. One proposal is that if a product or chemical cannot be recycled, it should not even be made.

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

A Logging Model

Another environmental problem which can be looked at with a model and simulation is cutting logs in forests. The question in 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 sustainable?

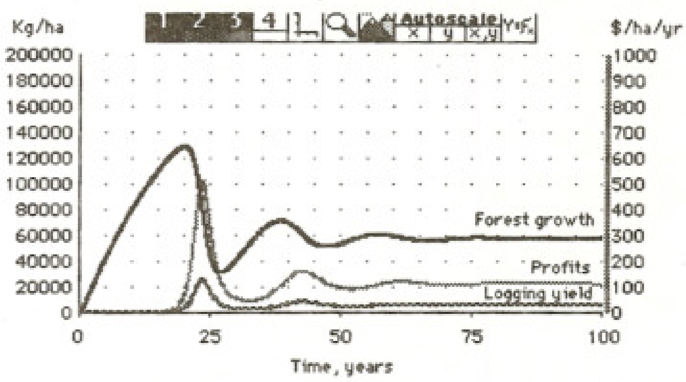

Figure 8

A simulation of the logging system over 100 years is shown in Figure 8. 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 years. The owner or investor may be interested in the long-run money to be made.

In this model changes of prices can be put in "what if" experiments. For example, what will the yield of logs and

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money return be if the selling price for logs doubles? Figure 8 is the run with original prices and quantities. 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? In Japan the average quantity of goods which people can buy for the dollar is less than in the U.S. If we sell our logs to Japan and spend the money to buy Japanese goods, this trade is equal in money. But, when you look at the exchange of real goods, the trade is to Japan's advantage. □

Notes

1. EXTEND is a general purpose simulation modeling program available from Imagine That Inc., 7109 Via Carmela, San Jose, CA 95139.

2. This work was done as part of the BioQuest project, centered at Beloit College. The systems symbols for use with the program EXTEND are available from Center for Wetlands, Phelps Laboratory, University of Florida, Gainesville, FL 32611.

References

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Balance of the Planet

Simulation by Chris Crawford
Software review by David Krieger

The icon on the desktop lets you know you're taking on a prodigious task: there's Mother Earth, cradled in two huge hands—yours. This is Chris Crawford's "Balance of the Planet," and you have been appointed "High Commissioner of the Environment" by the United Nations, with powers to tax industries and disburse subsidies toward the goal of preserving the ability of the Earth to support life. Your policies are implemented over five-year turns, and the results presented to you: did more or fewer people starve due to your actions? How many skin cancers resulted from the deteriorating ozone layer? Did the level of the oceans rise or fall due to global warming and polar melting? How many species became extinct?

In "Balance of the Planet", Chris Crawford, author of the popular Cold War simulation "Balance of Power," has designed a sophisticated and challenging introduction to the complexities of environmental policy and even ecological science. The game was released on Earth Day, April 22, 1990, to promote ecological awareness and stimulate discussion. If, like me, you found most of the media "events" associated with Earth Day to be trivial, embarrassing (the tons of trash left behind at Earth Day rallies, for example), or just plain dumb, you will revel in "Balance of the Planet" for bringing some rigor to the discussion. It's a meaningful way to promote the objectives of Earth Day.

How The Game Is Played

You are awarded points based on the state of the Earth: positive points for things like diversity of species and a sustainable energy economy; negative points for evils like starvation and devastation of the forests. The game starts you out in 1990 with zero points; the various plus and minus factors are all mutually balanced. This is deceptive: one of the central points made by the simulation is that things are already bad and getting worse, and it will take years or decades of dedicated effort to turn them around. No matter what course you choose, the results of your first few turns will be uniformly dismal, with your score diving into thousands of negative points. You have until 2035 to turn things around. A positive score at that time wins; a negative one loses.

"Balance of the Planet" bestows on you the power to tax various products that affect the environment, such as fossil fuels, chlorofluorocarbons (CFC's), heavy metals,