Computer Simulation of a Three-level (Tritrophic) Food Chain

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Summary of Activity

This module is a part of an Aquatic Ecology Exercise used in an introductory biology course. This computer simulation uses Excel worksheets with “Macros” coded in Basic associated with the worksheets. For discussion of potential modifications and extensions for other courses see Extensions and Options below.

Integration of Disciplines

Biology and Computer Science.

Although researchers in every branch of biology use computers for a variety of tasks, ecologists are probably the most dependent on information science (including statistics) and computer technology. Ecological systems are complex with many components—a diversity of abiotic variables, spatial and temporal heterogeneity, and most importantly, the presence of other species (as food, as competitors, and as predators) all affect the population dynamics of every species. Because many ecological processes occur over time-scales of years, decades, or even longer, computer modeling and data analysis is often the ecologist’s only recourse in studying the long-term behavior of communities/ecosystems.

Learning Objectives

- To understand the dynamics of food-chain population interactions
- To demonstrate the use of computers to model complex systems
- To assess the relative importance of different ecological factors on population sizes and what aspects of population life history make a species most vulnerable to extinction
- To serve as analytical tool to help students interpret their data from the Aquatic Ecology experiment

Target Level

This module is intended for undergraduates enrolled in an introductory biology course, but is suitable for all science undergraduates. Engineering students should be comfortable with the mathematical formulism and should be encouraged to do their own modifications of the basic model. To carry out and interpret the basic module requires no prior computer expertise and no knowledge of fundamental ecological principles. The output routines, especially the graphs, should *not require* modifications if innovations in the underlying ecological model are made, so this makes this teaching module particularly user-friendly.

Tools and Materials

- Textbook: Campbell NA and Reece JB. 2005. Biology, 7th ed. Pearson Education (Benjamin-Cummings)
- Student handout (must be downloaded on each student's computer) http://bioengineering.union.edu/ecologymodule/ecologystudent.pdf
- Worksheet (must be downloaded on each student's computer) http://bioengineering.union.edu/ecologymodule/FoodChain.xls
- Computers with connection to Union College Bioengineering Website http://bioengineering.union.edu
- Excel software
- Color printer (optional)

Theory and Background

Most introductory ecology textbooks present the basic theory and display experimental data on simple prey-predator interactions but go no further. Ricklefs (2001) presents no quantitative equations for even the simplest food chains, discusses energy flow and trophic pyramids in a general framework, and briefly introduces the basic Lotka-Volterra equations for the two-species case (no carrying capacities, no satiation effects, etc). Molles (2005) discusses trophic levels only in the context of specific ecosystems (trophic "cascades" in a fresh-water community and energy flow in the Serengeti) and also presents only the simplest form of the prey-predator equations. The three-level food chain exhibits more complex behavior, and in some cases paradoxical outcomes.

This exercise focuses on the cyclical nature of prey-predator dynamics and the question: does the ecosystem evolve over time to an equilibrium in which all three species persist as cycles diminish or does the ecosystem show instability with increasing amplitudes of population oscillations causing the eventual extinction of one or more of the component species. The basic module presented in introductory biology courses provides insight into the simple aquatic ecosystem involving algae, two categories of small invertebrate prey, and a fish as the top predator.

May's monograph, although not recent (1973), is still an excellent source for intermediate-level analyses and theory. Papers by Hastings and Powell (1991), Rinaldi and De Feo (1999) and Diehl and Feissel (2000) discuss the special cases of tritophic food chains in a more advanced context. McCauley et al (1999) may also be relevant in the specific context of the Aquatic Ecology exercise in Biology 110.

Safety Precautions

None.

Miscellaneous Advice to Instructors

1. This module as presented is carried out in two lab sessions, but takes only a small portion of the in-class time in each. It is feasible to do the entire exercise in one lab without the brief “hand-in” assignment. The advantage of using two labs is that the students will have collected their experimental data before they discuss the simulation results.
2. This module supplements the Aquatic Ecology experiment performed in Biology 110 at Union College and the student’s analysis of the simulation results is at a rudimentary level. Instructors should feel free to ask more questions of their students if time and interest permits; they might borrow from the suggestions offered for other courses in Part III below.
3. For some students, **any** equation is intimidating (even $A = \pi r^2$); however these equations are simple algebraic expressions and we have written them as difference equations rather than as differentials so a knowledge of calculus is not required (and difference equations are required in the programming within the macros, so the correspondence is exact).
4. The Aquatic Ecology experiment consists of replicated large-volume (30 liters) cultures of algae, various invertebrates, and one or two fish (see Appendix A in the student handout). In these cultures the fish do not reproduce and therefore are **not** a population variable as they are in the simulation. However, the small invertebrates in the cultures fall into two classes: rotifers, which feed on algae, and crustaceans, which feed on the rotifers (which in turn are eaten by the fish). The instructor should emphasize that both the experimental populations and their computer analogs represent tritrophic systems. What the students should see from the simulations is the cycling dynamics and the dependence of final population sizes on the values of the seven population parameters. Because students count the experimental populations just once at the end of the term, these aspects cannot be evaluated from the experimental data. Alternatively, the program could be easily altered so that the fish populations remain constant (neither die or reproduce) as is the case in the experiment.
5. The program allows for immigration by crustaceans into the ecosystem and for density-dependent death rates for the fish. These two aspects are ignored in the basic model but provide additional realism and three additional experimental parameters (see Extensions and Options).

Extensions and Options

The following are suggestions for ways in which this module can be enhanced for use in upper-level biology courses such as Ecology and Conservation Biology.

1. Ecology

Several investigations can be conducted at a somewhat more advanced level without modification of the program:

a. Which parameters most influence the period (or frequency) of the population cycles?

b. What are the consequences of changing the starting numbers for the three populations?

c. Is there is synergistic effect when more than one parameter is varied from its default value?

With minor modifications of the program, it is easy to evaluate the effects of different density-dependent death rates for the top [fish] predators or to vary the immigration rate of the crustaceans [these two enhancements would also be relevant for the Conservation Biology below].

An advanced exercise would incorporate time-lags into the model by modifying the Macro coding; as written, the model is unrealistic in that the consumed prey are “converted” into predator births in the next time interval (as if a wolf that has gorged itself on an elk at time T immediately gives birth a litter of pups at time T + 1). A more realistic version would, for example, make crustacean reproduction at time T depend on number of algae consumed at time T – L (where L is an integer greater than 1).

2. Conservation Biology

These additional questions are especially pertinent for investigations into the causes of local species extinction:

a. Which parameters most influence cycling period and magnitude?

b. Is it possible to modify the model by adding additional species so that the risk of extinction of a prey species is minimized by *predator-switching*?

c. A more realistic model might incorporate constraints (or trade-offs) in parameter values resulting from interactions between various components of the model. For example, because of foraging risks, an increase in the value of p_A, which increases the effective rate of predation by crustaceans on algae, may necessarily entail an increase in D_C.

References

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