

# Development of a Food Web Model (DOVE- Digital Organisms in a Virtual Ecosystem) to Examine Indirect Interactions in Food Webs and Invasive Species

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## Overview

Conventional food web models omit phenotypic plasticity and evolutionary history, two features of ecological communities that likely have a large influence in the structure and dynamics of Great Lakes food webs. I am using new computational methods to develop a modeling approach of food webs that allows the incorporation, and examination of the importance, of these features. A computational system, called “Digital Organisms in a Virtual Ecosystem” (DOVE), will use evolutionary algorithms (developed in computer science) to represent individual organism behavior in an individually based model. Simulated natural selection allows species to evolve, and solve the complex problem of persistence in the presence of multiple tradeoffs. I will use DOVE to study problems concerning contribution of predator-induced changes in prey phenotype (including behavior) to the net effect of predators and invasive species.

There are two principal initial goal applications of DOVE:

1. General: Examine how phenotypic plasticity affects food web properties, such as competition and invasion.
2. Specific application: Examine how phenotypic responses of zooplankton to the invasive predator cladoceran affect zooplankton population growth rate, and indirectly other species in the system (including young-of-year fish).

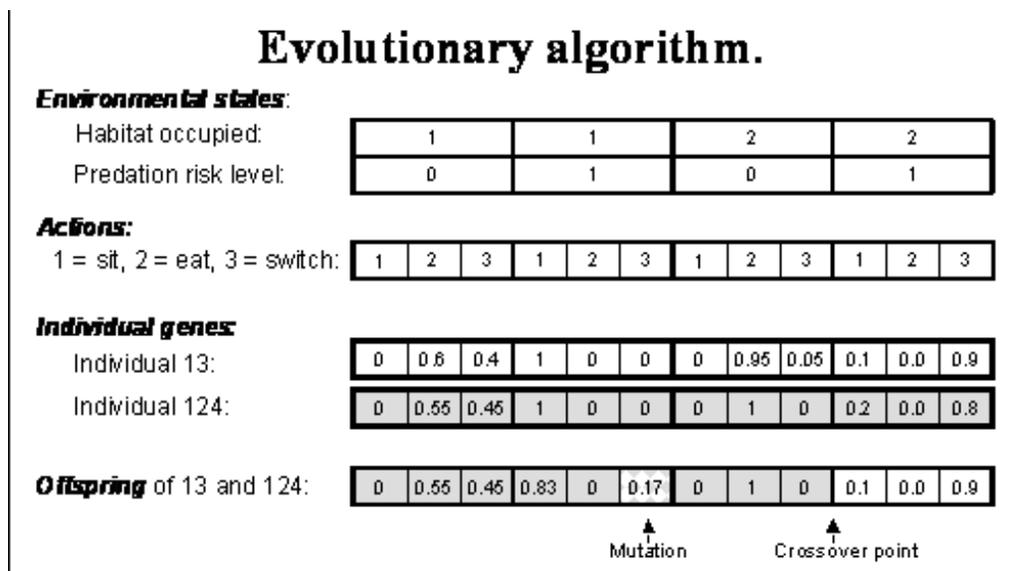
## A New Computational Model: Digital Organism in a Virtual Ecosystem (DOVE)



We are developing a computational model to examine food webs. The computational model is designed to address the challenges associated with the complexity of ecological communities

listed above that are difficult to impossible to address with traditional approaches. We plan to apply this model to two problems concerning Great Lakes food webs.

The computational model (called DOVE - Digital Organisms in a Virtual Ecosystem) draws on new computational techniques being developed in computer science and the multidisciplinary field of complex systems research. In particular, DOVE is an agent-based model (ABM, also called individually based models) which simulate the multiple interactions between individual “agents” (i.e. an individual fish) and the environment. Individual agents are given rules that describe their interactions with each other and the environment, and the population properties “emerge” rather than being determined by global parameters set in the model. Agents are typically heterogeneous, with trait frequencies varying in both space and time. An example of an ABM is SORTIE used to examine forest dynamics. Further, the organism’s behavior in DOVE will be determined by evolutionary algorithms, for example Genetic Algorithms (GAs). GAs are abstract models of Darwinian evolution by variation and selection of heritable traits (Holland, 1975, 1992). With genetic algorithms, a solution to a problem is given a genome (or chromosome). The genetic algorithm then creates a population of solutions and applies genetic operators such as mutation and crossover to evolve the solutions in order to find the best one.



DOVE will be a computational system that allows the construction of relatively persistent “virtual ecosystems” of multiple interacting populations of digital organisms species. Each “species” will have solved the problem of surviving on a complex landscape with multiple predators, competitors and resources in unique ways. For example, the digital organisms, like their real organism counterparts, face a tradeoff between acquiring resources and being preyed upon when they move to search for resources. Some species will likely solve this problem by conserving resources and avoiding risk, while others will move rapidly in order to attain high reproductive rates at the cost of high mortality due to predation. There also may be much variation in the structure of the persistent communities.

## 2006 Accomplishments

### **DOVE Code Development:**

To examine “invasion biology” we added a feature that allows the invasion of propagules of an “invader” species:

- Single-habitat world only
- Invasion after anti-extinction period
- New parameter added to control how many individuals invade each timestep
- Once they invade they behave normally
- Added more options to control invaders
- 3 new control parameters
- Controls gene-matrix values
- Added new parameter for Conversion Efficiency (this parameter allows us to add the cost of converting food into biomass. It was needed to examine the “cost” of plasticity in the PloS biology rewrite)
- Added new Global Predator frequency option
- “Discrete-state Markov Chain” method
- Re-uses existing parameters with new interpretation for quick implementation
- Added new method for choosing animal action: (this is a major endeavor, and important for future implementation. This change moves us away from the “matrix” like behavioral algorithm, to a morecontinuous algorithm. That is, for example, a consumer will respond to continuous changes in predator density, rather than discrete)
- Added to Stefano’s Dove (not DoveA)
- Equation-based rather than gene-matrix (not yet fully tested)
- Work on improving parameter handling and general program organization
- Design work toward improving organization, adding needed functionality and streamlining existing functionality

### **Parallel Model Development**

Similar to all individually based models, DOVE is complex, and therefore it is helpful to build and analyze more simple parallel models. This serves two principal purposes.

First, it allows for a test of DOVEs implementation in more simple cases - that is, a way to find bugs.

Second, it allows comparison of DOVE to more traditional cases. We have continued to develop two parallel approaches that were started last year. First, a differential equation based model that can predict equilibrium densities of consumers and resources in very simple scenarios. And second, a Stochastic Dynamic Programming (SDP) model, that is in initial stages of development. We have applied these models to the Lake-Michigan *Bythotrephes-Daphnia* system that Peacor studies with graduate student Kevin Pangle. Initial results are indicating that the observed migratory response of *Daphnia* is adaptive (and similar to model predictions). We are able to disentangle the relative contribution of nonlethal effects of

*Bythotrephes*, and find that it is a substantial contribution of its net effect on *Daphnia* population growth rate.

### **DOVE implementation**

A paper was submitted to PloS Biology based on DOVE results on how phenotypic plasticity affects invasion biology. The paper was accepted in this highly regarded journal.

### **References**

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Werner, E. E. and Peacor, S. D. 2003. A review of trait-mediated indirect interactions. *Ecology* 84: 1083-1100.

### **Products**

#### **Publications**

Peacor, S. D, S. Allesina, T. S. Hunter, and R. L. Riolo. A new computational system, DOVE (Digital Organisms in a Virtual Ecosystem), to study phenotypic plasticity and its effects in food webs. *Ecological modeling*. Accepted pending revisions

Peacor, S. D, S. Allesina, R. L. Riolo, and M. Pascual. 2006. Phenotypic plasticity opposes species invasions by altering fitness surface. *PLoS Biology* 4(11): e372.

Peacor, S.D., R. Riolo, and M. Pascual, 2005. *Phenotypic plasticity and species coexistence: modeling food webs as complex adaptive systems*. (Book chapter, submitted, 2004)

#### **Poster**

Scott Peacor, S.D. and R. Lanfear. 2003. *Digital Organisms in a Virtual Environment (DOVE)*. Center for Biological Modeling Biological Networks Symposium. Michigan State University, East Lansing, MI.

#### **Presentations**

Button, K. A., Pangle, K. L., and Peacor, S. D. *Prey responding adaptively to an invasive predator: relative importance of trait and density effects*. Michigan State University Invasive Species Symposium, East Lansing, MI. May 2006. (Recipient of best student poster award)

Peacor, S.D., S. Allesina, R. Riolo, and M. Pascual. *Phenotypic-plasticity increases species coexistence by changing the steepness of an adaptive landscape*. 90th Annual Meeting of the Ecological Society of America, Montreal, Quebec, August 2005.

Peacor, S. D., S. Allesina, R. Riolo, and M. Pascual. *Phenotypic plasticity and species coexistence: modeling food webs as complex and adaptive systems*. Kellogg Biological Station, Michigan State University. Hickory Corners, MI. April 2005.

Peacor, S. D., S. Allesina, R. Riolo, and M. Pascual. *Phenotypic Plasticity and Species Coexistence*. Netherlands Institute of Ecology Centre for Limnology, Nieuwersluis, The Netherlands. June 2005.

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Workshop at Santa Fe Institute, Santa Fe, NM. "*From Structure to Dynamics in Complex Ecological Networks*".

- a) Peacor, S.D. 2004. "*Phenotypic plasticity and trait-mediated indirect interactions*"
- b) Peacor, S.D., R. Riolo, M. Pascual, E. Goodman and J. Holland. 2004. "*Computational System to Examine the Origin and Effects of Phenotypic Plasticity in Food Webs*"

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