ECOME: A simple model for an evolving consumption web.

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Abstract

ECOME is an interactive, graph-based model for simulating an evolving, closed consumption web. It demonstrates the fundamental behavior of a global ecosystem over evolutionary time using well-established ecological/evolutionary principles. Nodes in the graph send biomass along weighted, directed edges. New nodes evolve by speciation and disappear when biomass (i.e. population) shrinks to zero. Consumption rates, predator/prey relationships, and speciation rates are user-defined, following theoretic distributions. The output shows the biomass and biodiversity over time for up to five trophic levels. Using this simple system, we demonstrate that closed ecosystems are inherently unstable in the absence of evolution or in the presence of a single, hyper-changing species, but are dynamically stable and robust to perturbations when the evolution rates for all species follow a normal distribution. Our new application provides provocative lessons for biology students during a time of mass extinction.

1. Introduction

The Earth is a gigantic, evolving food web where carbon units (biomass) are transferred from the atmosphere to plant species (producers), from all species to animal species (consumers), and from all species back to the atmosphere (decay/respiration). Understanding the dynamic nature of a global ecosystem over evolutionary time can teach us lessons that may help lead us to a sustainable human existence.

The ECOME Project is an exercise in reproducing known ecological phenomena using the simplest possible model and the fewest number of variable parameters. The model is a "consumption-web". Consumption includes but is not limited to the assimilation of biomass from other species, but can be any activity by one species that leads to the death or decay of itself or another species. (We don't eat trees, but we certainly consume them.) The net effect of consumption is the transfer of biomass from one species to another and then back to the atmosphere via respiration or decomposition. This simple model captures the fundamental forces governing population dynamics without the complicating or irrelevant factors such as migration, life cycles, spatial distribution, and individual organisms. These characteristics and others can be modeled in a broad-brush way by defining theoretically-reasonable kernel functions. Examples of kernel functions and what they represent are presented here.

2. Methods

2.1. Structure of the consumption web model

The model is a directed graph where each node represents one species. Species have two types: producers (plants) and consumers (animals). *Producers* grow exponentially at a fixed rate until a global nutrient limit is reached. *Consumers* consume biomass from prey species at fixed rates. They grow exponentially as long as prey is available. A third type, *decomposers* are not modeled as separate species but rather are expressed as a fixed rate of biomass loss (decay). Decay and respiration are functionally the same process.

2.2. Simulation cycle

At each simulation cycle, the populations (biomass) are updated for each species *i*, as follows:

population(i) = *old_population*(i) + *newC*(i) - *lostC*(i)
where,
newC = biomass produced or consumed in one cycle.
lostC = biomass lost, either by decay or by predation.

Biomass gained and lost are calculated using species-specific growth and decay rates and predation rates. For example, for plants:

$$newC(i) = old\_population(i) * growth(i)$$
$$lostC(i) = old\_population(i) * decay(i) + \sum_{j=predators} consumedC(i,j)$$

where the amount of *i* consumed by *j* depends on the population growth of *j* and the fraction of *j*'s diet consisting of *i*,

$$consumedC(i,j) = old\_population(j) * growth(j) * consumption(j,i)$$

Similar equations were written for animal species, but *newC* includes biomass from prey species. Throughout the simulation, the biomass bookkeeping is kept "honest" and each predator species gains exactly the amount of biomass that is lost by the prey.

2.3. Speciation

At user-defined intervals, a randomly selected species is split into two with a 95:5 ratio. The smaller fraction adapt a new growth rate and a defense against a predator, or it may select a new prey resource if it is an animal.

2.4. Predator/prey response functions

The availability of prey as a function of population is modeled using Holling's response functions, of which there are three kernel types.

2.5. Simple models for human culture

Culture is defined as the ability of one animal species to adopt a new resource without speciation. That is, the new resource is immediately available to the whole population instead of just a small fraction of that population, as is the case with speciation. Four variants on this theme have been tried, reflecting perhaps, different levels of environmental consciousness.

CULTURE TYPE 1. *Innovation*. Humans are allowed to choose a new resource randomly, when they are starving. The likelihood of success in choosing a new resource is proportional to the fraction of the population that is starving.

CULTURE TYPE 2. *Trade*. Humans are allowed to choose a new resource randomly, when they are starving. However, the likelihood of choosing a new resource successfully is 100%. Here it is assumed that starvation anywhere in the world can be addressed by through "trade."

CULTURE TYPE 3. *Defense*. Humans are allowed to choose a new resource whether starving or not. The resource can be any predator of humans. Here humans are conscious of their own predators and "consume" them (e.g. drugs against disease predators).

CULTURE TYPE 4. *Conservation*. Humans have all of the abilities of Type 3 culture, and also control their own intrinsic growth rate. When starving, humans cut their growth rate in half, and when resources are available in abundance, the original growth rate returns. Here we are proposing human consciousness of available resources.

3. Results

3.1. Ecosystem robustness

Stability of the First Type: Over time there is a increasing constancy of numbers. The system will eventually reach a steady state under constant conditions.

Stability of the Second Type: The system has greater resistance to changes that are external. Perturbations lead to re-equilibration rather than collapse. Increased biodiversity, expressed as the entropy of the population distribution, correlates roughly with stability of the second type.

3.2. Zero speciation leads to ecosystem collapse

In the absence of any changes in predator/prey relationships, prey plants eventually go extinct, since they compete for light and nutrients with non-prey plants. When edible plant resources disappear, eventually all animals go extinct, leaving only plants. Speciation with adaptation allows non-resource plants to become resources. Holling's response functions can slow, but not stop, the process of collapse.

3.3. Human culture leads to human extinction

In this simple system, Culture of types 1 and 2 usually lead to the extinction of the "human" species, since rapid adaptation allows the species to reach a high population that eventually becomes a rich resource for other predators (i.e. disease species). Culture Type 3 leads to total ecosystem collapse plus extinction, since other predators no longer stand in the way of runaway population growth. Culture Type 4 leads to a sustainable human existence when combined with Cultures Type 1,2,3.

4. Availability

ECOME is available as a server/client web application or as a standalone for several operating systems. A GUI allows the user to change parameters and perturb the system while watching the population dynamics. ECOME is freeware.