Modeling trophic dynamics in the CAP area

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Summary

Water is usually the limiting resource for plant productivity in the Sonoran Desert. In the Central Arizona Phoenix area (CAP), urbanization generally leads to increased and more stable water availability, resulting in increased plant productivity. Several research projects are presently underway that explore how this changing water availability affects ecological communities, with emphasis on plant productivity, arthropod and bird species diversity, and composition. We explore these issues using simple mathematical models. These models will be later integrated and validated with data from CAP empirical studies. The models assume water as the limiting resource, thereby directly influencing plant carrying capacity. The simplest model is a tri-trophic system with a linear functional response on herbivore and predator level. The second model is similar, but with a type II functional response on the same levels. The third model consists of producer, herbivore and an omnivore level, the two last with type II functional response. All models are able to incorporate bird predation on both consumer levels. The models are compared using bifurcation analysis, focusing on plant carrying capacity, trophic biomass and predation by birds. The models give results that are easily testable in field experiments, and this work provides a good foundation for integrating empirical data from the CAP urban ecosystem.

Discussion

While the dynamics of these models have been studied by e.g. Rosenzweig (1973), Murdoch and Nisbet (1974), Abrams and Rohr (1994), McCann and Yodzis (1995), we aim to extend this theoretical work and apply it to an actual system to learn more about what makes places in the real world tick. The work introduced here represents the first step in that direction, as we show that different simple models can predict almost identical dynamics within reasonable parameter boundaries. Varying the carrying capacity indirectly reflects different levels of water availability, which is typical for the CAP area. All the models give predictions that will be simple to measure empirically in controlled field experiments. For example, all the models show the same response to variation in carrying capacity, which may be reflected by different degrees of urbanization. At intermediate levels of water availability we may expect to find low levels of plant biomass, and almost no predators. In a natural system, arthropod predators have a higher motility and can move between plants. This is not considered in these models, and may explain individuals of predators on plants even if the water availability is low. In urban areas with high water availability, we may expect to find high abundances of predators. The models do not distinguish significantly between predators and omnivores, thus the complexity of Model 3 may be superfluous for later analyses.

Background

Our knowledge about control of food web structure in urban communities is limited, despite it being the most rapidly expanding type of ecosystem in the world. However, in Phoenix and other LTER sites we start to learn more about trophic dynamics in cities. In dry and environments like the CAP area, habitat productivity increases with urbanization as a result of irrigated lawns and parks, and arthropod species diversity and composition are altered (Rango 2002, Shochat et al. 2004, Faeth et al. 2005, Cook and Faeth 2006, Shochat et al. 2006). Urbanization affects trophic structure partly by removing members of higher trophic levels (Cook and Faeth 2006), but the complex dynamics are not predictable based only on species composition (Shochat et al. 2006). Conflicting results from estimating the risk of predation of and in urbanized areas raise a question of how important is top predation in regulating trophic dynamics (Shochat et al. 2006).

Mathematical models have been used for decades to explain relationships within populations, communities and trophic levels. Despite the many assumptions and approximations that make simple models can it easier to understand complicated ecosystems (e.g. Hilborn and Mangel 1997, Murdoch et al. 2003). We believe that mathematical models can contribute to the understanding of complex trophic dynamics in urbanized communities. We compare different simple trophic model systems based on parameter values assumed to be appropriate for the CAP LTER area. Our goal is to integrate empirical data in the best fit model.

Results

All models were run until stable conditions where reached. At this equilibrium, we plotted the equilibrium biomass as a function of carrying capacity (Figure 2). This revealed several bifurcation points, which were analysed with two parameters, bird predation and carrying capacity. Some of these analyses are shown in Figure 3.

Not surprisingly, the dynamics of all the models are relatively similar. Typically, low carrying capacity supports only the plant trophic level, and the plant biomass follows the growth in carrying capacity linearly. As the carrying capacity increases, the system supports more trophic levels. The plant biomass stagnates when the herbivores enter the system, but then continues to increase when the carrying capacity is high enough to support either predators or omnivores.

The differences between the models are easily detected at the top trophic level, where predator biomass increases linearly in Model 1, reaches a saturation level in Model 2, and the omnivores in Model 3 get a second bifurcation point. Notice however, that the top level response is only visible outside the realistic boundaries of the model. The other differences lie in the slopes of herbivore and plant biomass after the introduction of the third trophic level, where the plant biomass increases more rapidly and herbivore biomass decreases slowly in Model 3.

The two bifurcation figures confirm that bird predation and carrying capacity limits the degree of co-existence in the analyzed system. Exclusion experiments along with different water treatments on plants are currently being carried out, and will tell us if these predictions are reliable. Experiments to determine functional responses for herbivores, arthropod predators and omnivores, thus the complexity of Model 3 may be superfluous for later analyses.

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References


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Figure 1: Three food webs explored by mathematical models. The arrows indicate the direction of energy. The dashed arrows indicate that bird predation is optional to simulate exclusion experiments.

Figure 2: Solution branch diagrams of the three different models. Change in trophic biomass is on the second axis, while carrying capacity varies along the first axis. Solid lines indicate stable conditions, while the dashed lines indicate unstable conditions. Notice different scales on the top trophic level.

Figure 3: Two-parameter bifurcation diagrams of the three models. Three different areas, A, B and C are similar for all the models: A) Only the plant level can exist. B) Plants and herbivores co-exist, and C) all three levels coexist.