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Identifying, preventing and controlling invasive plant species using their physiological traits

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Abstract

A model of a plant community that is biologically reasonable and easily adaptable to economic models is presented. The model includes optimization, competition, stochastic limiting resources, and identification of redundant and invasive species. Species exhibit a rich array of traits that make them suited for some set of environmental factors and not for other sets. And because environmental factors are constantly changing, species that are very successful under one set of factors become redundant under another set, implying that an ecosystem needs redundant species as insurance. Invasive species are the flip side of redundant species as they are successful, at least under some environmental conditions. Identification depends on four physiological parameters defining each plant: two respiration parameters, a parameter that gives the plant's ideal level of the stochastic limiting resource, and the specific leaf area. The parameters are terms in an expression that gives the net energy intake of an individual plant, and the plant behaves as if it optimizes this by choosing its individual biomass. Success of species is judged based on the biomass of the species in steady state. An application extends the range management literature by incorporating the model into a rangeland manager's decision problem extends the range management literature. The model allows for multiple plant species, addresses the influence of limiting resources (other than density dependence), and tracks the response of the entire system to human and natural system perturbations. The methods allow simple predictions of community composition in the face of jointly determined economic/ecological behavior. The power of the method is demonstrated through stylized examples of alternative invasion control techniques.
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1. Introduction

Invasive species—harmful species introduced from elsewhere—are increasing worldwide, contributing to biodiversity loss and environmental change. Resource managers are being challenged to answer key policy questions of how to allocate society's resources to combat invasive species, and how best to mix ex ante and ex post strategies. To do a reasonable job, managers require knowledge of both economic and ecological systems. Human activities invariably impact ecosystems. The ecosys-

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tems respond to the impacts, in turn causing new human activity, and the process repeats. Capturing this linked economic system–ecosystem interaction requires one to account for adaptation and feedbacks within and between the systems. The issues are substantially complicated for the case of invasive species, where accurate predictions of biological system response to invasion are critical to efficient management. The ecosystem consequences of invasion can be better understood by recognizing that species exhibit a rich array of traits that make each of them ideally suited for some set of environmental factors and species composition and not for other sets and compositions (an early example is Gutierrez and Yaninek, 1983). Because environmental factors and species composition change over time, successful and unsuccessful species, including invaders, may trade places. Less successful species can be viewed as providing biodiversity insurance for the day when environmental factors or species composition change and the less successful replace the previously successful. We refer to these backup species as redundant. At any point in time, if a species is redundant in the community, it cannot be a successful invader, whereas a species that is a successful invader cannot be redundant.

In this paper a theory is developed and applied in a range management setting that can be used for identifying redundant and successful invasive plant species. Identification depends on four physiological parameters defining each plant: two respiration parameters, a parameter describing the plant's solar energy intake, and a parameter that gives the plant's ideal level of an environmental factor. The parameters are terms in an expression that gives the net energy intake of an individual plant, and the plant behaves as if it is maximizing this net energy by choosing their individual biomass.[1] The major difference between the theory presented here and most

other theories of plant population dynamics is what underpins the population update equations. Most other theories take the update equations as their starting point. The equations include state variables for species populations, and they are formed by assuming that the changes in a population depend on the populations of other species in the community and on resource availability.

In the plant community model herein, the theory starts prior to population updates by first assuming the individual plant behaves as if it is choosing its optimum biomass. Optimization is done given the plant's parameters and the presence of other competing plants in its own and other species. The optimum amount of biomass is found to be where the marginal energy gain from growing another unit of biomass equals the marginal energy loss to respiration from that unit. The success of the individual in processing energy efficiently determines the species growth rate in the update equation.

The plant community occupies a fixed space, and as plants grow more biomass and/or become more numerous, the space fills up. As the space fills, each new unit of biomass grown becomes less effective in absorbing energy owing to shading from other plants. The loss in effectiveness is labeled the shading energy loss (SEL), and it represents the "price" the plant must pay to obtain energy. No single plant has any control over the SEL because it is only one of many plants in its vicinity and the value of the SEL depends on the aggregate action of all plants. Specifically, SEL is determined by equating the sum of all plants' optimum biomasses, or their "demands" for biomass, to the supply of space. When there are few plants in the space, SEL is zero and there is no competition. As plant biomasses and populations increase, however, SEL turns positive, and the greater the aggregate biomass demands, the greater is SEL and the more intense is the competition.

Populations change according to the success of the plants in storing net energy, and their optimum net energy is inversely related to SEL. Thus, when there is no competition and SEL is zero, net energies are positive and the populations grow. When there is competition, SEL turns positive and net energies fall. If they fall below zero, populations shrink. The interaction between the plants' demands and the supply of space tend to move net energies to zero and to a steady state.

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[1] Gutierrez and Baumgärtner (1984), Gutierrez (1992), and Gutierrez et al. (1994) present a similar method, where genetically determined maximum demands are constrained by current ecosystem conditions. Realized demands (realized functional responses) in the short-run depend on a parameter describing the accessibility of prey to the predator, and the ratio of the prey mass to the predator mass. For given maximum demands and levels of accessibility, the functional response is determined solely by the mass ratio in the absence of any optimization.