Biological Control Through Intraguild Predation: Case Studies in Pest Control, Invasive Species and Range Expansion

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Abstract Intraguild predation (IGP), the interaction between species that eat each other and compete for shared resources, is ubiquitous in nature. We document its occurrence across a wide range of taxonomic groups and ecosystems with particular reference to non-indigenous species and agricultural pests. The consequences of IGP are complex and difficult to interpret. The purpose of this paper is to provide a modelling framework for the analysis of IGP in a spatial context. We start by considering a spatially homogeneous system and find the conditions for predator and prey to exclude each other, to coexist and for alternative stable states. Management alternatives for the control of invasive or pest species through IGP are presented for the spatially homogeneous system. We extend the model to include movement of predator and prey. In this spatial context, it is possible to switch between alternative stable steady states through local perturbations that give rise to travelling waves of extinction or control. The direction of the travelling wave depends on the details of the nonlinear intraguild interactions, but can be calculated explicitly. This spatial phenomenon suggests means by which invasions succeed or fail, and yields new methods for spatial biological control. Freshwater case studies are used to illustrate the outcomes.

Keywords Competition \cdot Intraguild predation \cdot Mathematical model \cdot Biological control \cdot Travelling waves \cdot Reaction–diffusion \cdot Differential equations \cdot Range expansion \cdot Non-indigenous species

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1. Introduction and biological background

Interspecific interactions include competition and predation. The combination of these two is intraguild predation (IGP), defined as the killing or eating of species that use similar, often limiting, resources and are thus potential competitors (Polis et al., 1989). The importance and occurrence of IGP has been documented across taxonomic groups and is prevalent in nature (reviewed by Polis et al., 1989). Theoretical treatments of IGP suggest alternative stable states occur, such as two alternative stable equilibria (Polis et al., 1989; Holt and Polis, 1997; Mylius et al., 2001; Diehl, 2003), while experimental studies have confirmed theoretical predictions (Holyoak and Sachdev, 1998; Morin, 1999; Diehl and Feißel, 2000; Schroder et al., 2005). IGP is likely to occur in populations structured by size or stage (Ebenman and Persson, 1988) and where organisms undergo ontogenetic niche shifts, that is to say the patterns in resource use that develop as an organism increases in size from juvenile to adult (Werner and Gilliam, 1984).

Natural enemies are often employed as biological control predators for pest species, however IGP is common in biological control species interactions (for a review in arthropod and nematode communities, see Rosenheim et al., 1995). There are many examples in agricultural environments (see Table 1).

The alternative food source allows the biological control predators to persist even at times of low prey abundance, but the competition for resources weakens the predatory effect on the pest species. From the perspective of the prey species, IGP adds an additional detrimental effect, not only does the prey suffer mortality due to predation, but it also has less resource available due to competition. What are the consequences of IGP for biological control?

IGP can be observed in many interactions between exotic and native species (see Table 1). Examples can be seen across a wide range of ecosystems, such as brown tree snake and mangrove monitor, and rusty crayfish and smallmouth bass. A more detailed treatment of the interaction between rusty crayfish and smallmouth bass can be found elsewhere (Drury et al., manuscript in preparation). In both these examples, mutual IGP (Polis et al., 1989) is observed.

Given the prevalence of IGP in the interactions between pest species (native and non-indigenous species) and their competitors and natural enemies, how can the theory be employed to help inform the management and biological control of pest species? In order to address this question, we build a general model for IGP with an intraguild predator and an intraguild prey who compete for shared resources. We develop a mathematical model for the population density of the predator and prey as they change over time. Initially, we consider a spatially independent formulation of the problem and determine all possible outcomes of the dynamical system. We find the parameter regimes under which biological control of the exotic is possible (under manipulation of predator or prey or both) and deduce where perturbations are unlikely to change the steady state of the system.

Previous theoretical treatment of IGP in the literature has included different predation functional responses (linear and nonlinear) at different productivity levels. For example, a Type I functional response (Holling, 1959) has been used to model the predation interaction (Polis et al., 1989) and the possible dynamical outcomes described: exclusion of intraguild prey by the intraguild predator;