Modeling the compatibility of biocontrol and pesticides: spatial scale and predator behavior

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ABSTRACT

- Using coupled partial differential equations, we explore the effects of pesticide use and reduced predator movement on pest suppression across a gradient of farm spatial scales.
- We find that in small fields, landscape diversification schemes that increase natural enemy abundance can be beneficial, but in mid-sized fields, sublethal pesticide effects on predator mobility have the most detrimental impact on pest control by natural predator communities.
- Frequency of pesticide sprays needed to suppress pests was mediated by field spatial scale and predator mobility.

METHODS

- Pest population (e.g., aphids) grows logistically; diffuses aerially (due to crowding or disturbance) dies due to predation.
- Predator population (e.g., carabid beetles) diffuses while randomly foraging; directed movement towards prey initial population plus migration into field.
- Most pests (90%) die after spray; predators experience 90% reduction (penalty) in *diffusion speed* and *directed movement*.
- Threshold of aphid density triggers pesticide spray.
- Examine differences among:

  (i) varying field spatial scales and predator immigration rates, and

  (ii) different types of biocontrol (natural, beetle banks, augmentative).



The dynamics for the model are described by the following equations, where A denotes aphid prey, B denotes beetle predators, and B_s denotes beetles exposed to pesticide sprays:

$$\frac{\partial A}{\partial t} = rA\left(1-\frac{A}{K}\right) + \nabla\cdot[d_A\nabla A + d_{AB}(B+B_S)\nabla A] - \mu A(B+B_S) \quad \nabla A\cdot n = 0$$

$$\frac{\partial B}{\partial t} = \nabla\cdot d_B\nabla B - \nabla\cdot(VB) + M_I \quad \nabla B\cdot n = M_E$$

$$\frac{\partial B_S}{\partial t} = \nabla\cdot(1-\varepsilon)d_B\nabla B_S - \nabla\cdot(V_S B_S) \quad \nabla B_S\cdot n = 0$$

Table 1
List of model parameters, with biological meaning and values used in our simulations.

	Biological Meaning	Value	Source
r	Aphid growth rate	0.21	Mid-level growth rate from Asin and Pons (2001), selected for aphid populations to establish quickly but not at maximal rates
K	Aphid carrying capacity	10,000	Selected to greatly exceed A_{max}
μ	Consumption of aphids by beetles	1	Selected (with B_0) for aphid population similar to Curtsdotter et al. (2019)
d_A	Aphid diffusion (via winged alates)	8.87×10^{-6}	From Bommarco et al. (2007)
d_{AB}	Aphid diffusion increased by beetles	6.81×10^{-6}	From Weisser at al. (1999)
d_B	Beetle diffusion (via random foraging)	$[10^{-3}, 10^{-2}]$	Variability around observation from Allema (2014)
d_{VA}	Beetle movement towards aphids	$[10^{-9}, 10^{-7}]$	Variability not to exceed predator speeds from Wallin and Ekbom (1994)
d_{VB}	Beetle movement away from competition	10^{-4}	Scaled to balance (not outweigh) change in speed caused by d_{VA}
ε	Penalty to sprayed predator movement	0.9	Assumed efficacy
A_{max}	Aphid threshold for pesticide sprays	500	Assumed threshold
M_E	Beetle migration at field edge (natural)	[.1,.9]	Variability around beetle abundances from Curtsdotter et al. (2019)
M_I	Beetle addition to field interior (introduced)	–	Calculated to match average predator abundance from M_E



Table 2
Model implementation of assumed predator management strategies. Quantities indicated by (*) are calculated to match average predator densities from the natural predator community with $M_E = 0.9$.

Predator Management	Model implementation
Natural predator community	No predators in field initially Migration at field edge, M_E from 0.1 to 0.9 Migration begins after aphid colonization
Augmentative control	No predators in field initially Added to field interior, M_I at 322.05* Augmentation begins when aphid density is high
Conservation control	Predators initially in field at average density 0.359* Migration at field edge, M_E at 0.225* Migration begins after aphid colonization

RESULTS

- The frequency of pesticide sprays necessary to suppress aphids (triggered by threshold density) was mediated by beetle migration rates and field spatial scale.
- At 5 ha: fields with low and medium beetle immigration required frequent sprays, whereas at the same scale, fields with high beetle immigration were able to rely solely on biological control for pest suppression (Fig.1).
- At 50ha: frequency of required sprays varies with control strategies; augmentative control requires the fewest number of sprays, while natural and within-field beetle banks fared only slightly better than fields in which no predators are present (Fig. 2).
- Loss of biological control (increasing aphid density) relates linearly to pesticide-exposed predator movement, except for smallest and largest spatial scales, where increasing predator diffusion has a saturating effect (Fig. 3).

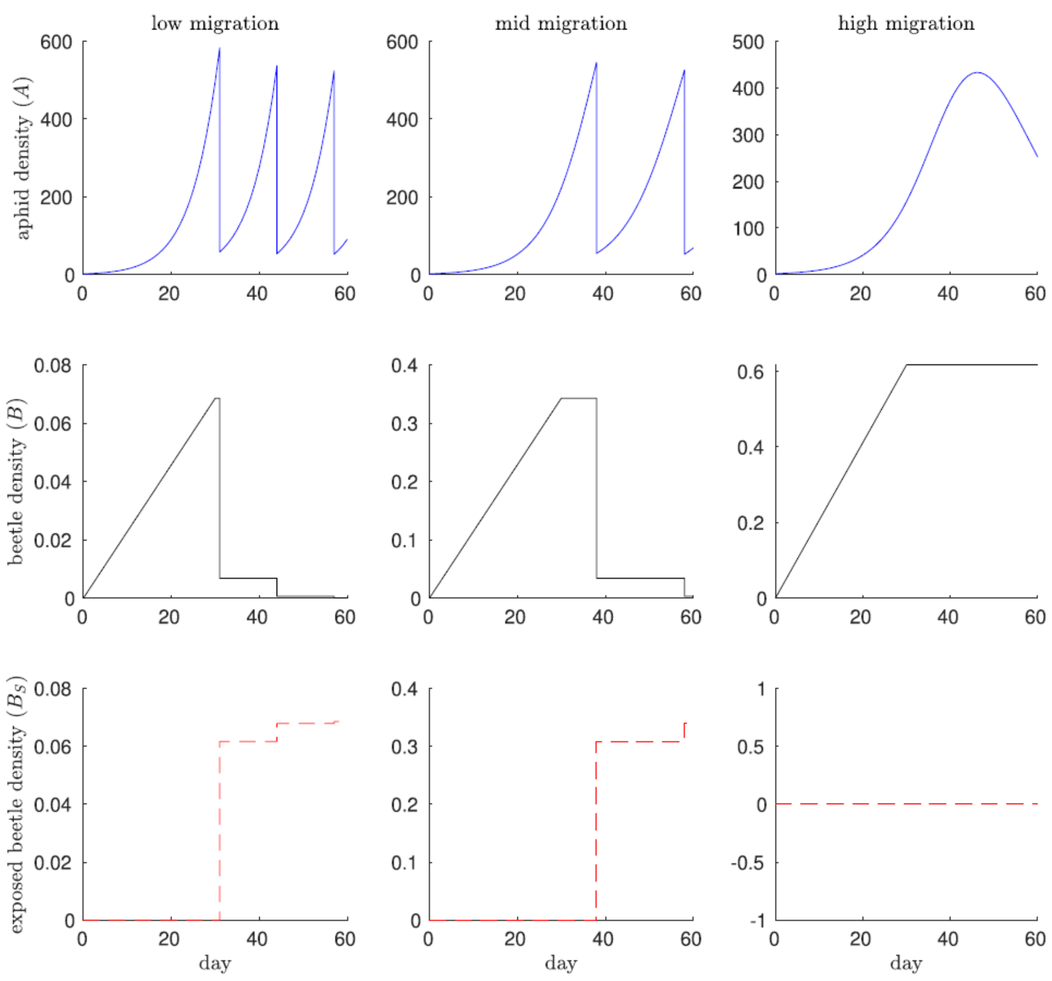


Fig. 1. Average population densities in a small 5 ha field over a 60-day season for aphids (top row), natural beetle predators (middle row), and exposed beetle predators (bottom row). The three columns correspond to different predator migration rates, ranging from low (left) to high (right).

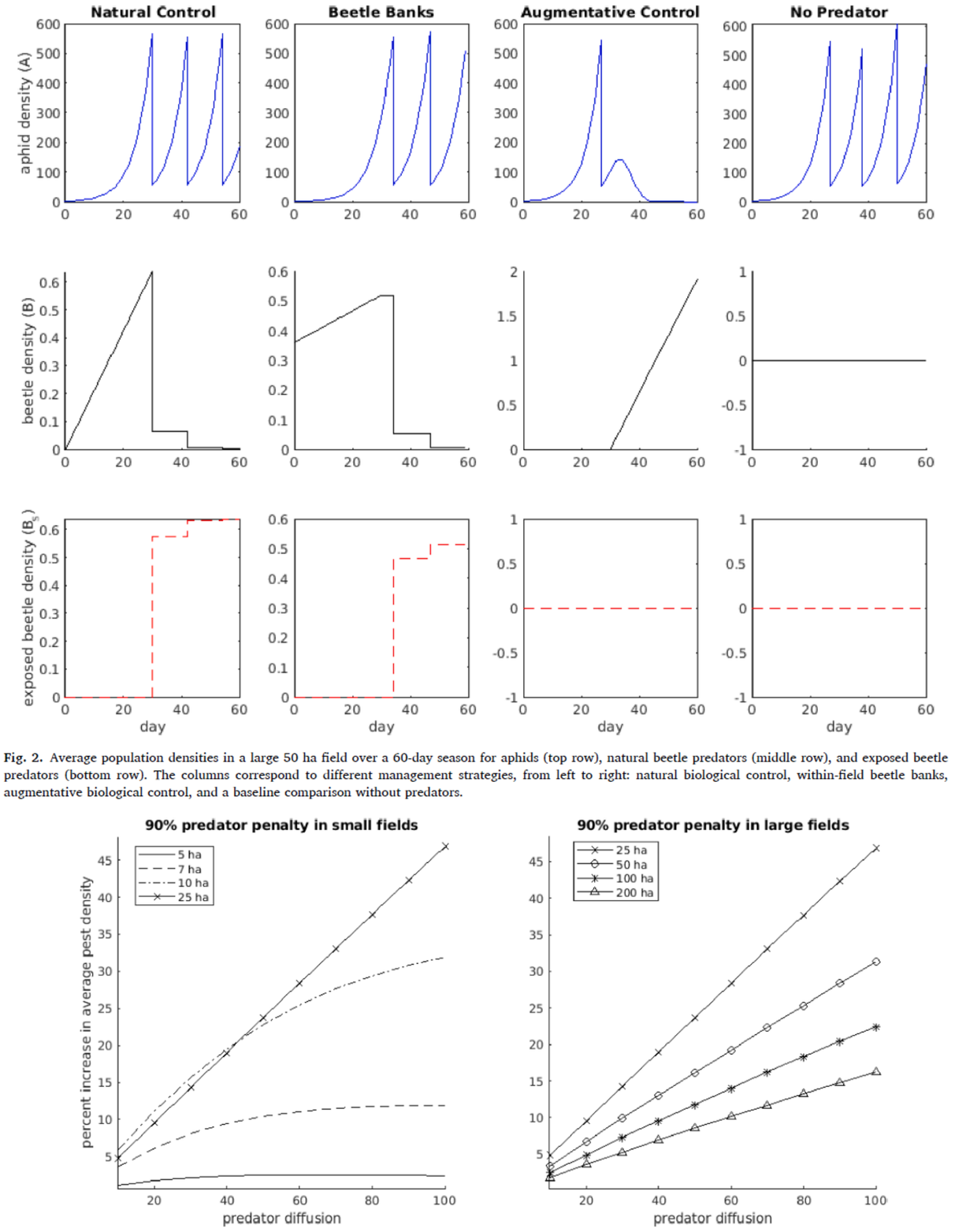


Fig. 2. Average population densities in a large 50 ha field over a 60-day season for aphids (top row), natural beetle predators (middle row), and exposed beetle predators (bottom row). The columns correspond to different management strategies, from left to right: natural biological control, within-field beetle banks, augmentative biological control, and a baseline comparison without predators.

Fig. 3. The percent increase in average aphid density when predatory beetles incur a 90 % movement penalty, compared to beetles without any movement penalty. The average is calculated across a 60 day season for a range of beetle mobilities (diffusion constant d_C) and differently sized fields. For readability, the left subplot shows results for smaller fields and the right subplot shows results for larger fields. Results for a 25 ha field are shown in both subplots, to facilitate comparison.

CONCLUSIONS

Compatibility between pesticides and biocontrol mediated by *predator mobility* and field *spatial scale*.

Intermediate scale compatibility: biocontrol disruption due to predator movement penalties not so important in **small** fields with highly mobile predators (*predators still able to control prey*); likewise disruption not that influential in **large** fields (*predator already struggle to suppress prey*).

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